OPERATION OF DYNAMO-ELECTRIC MACHINERY

INTERNATIONAL TEXTBOOK COMPANY
SCRANTON, PA.

Operation of Dynamo-Electric Machinery

International correspondence school

By

I.C.S. STAFF

OPERATION OF DYNAMO-ELECTRIC MACHINERY
Parts 1–2

444

Published by

INTERNATIONAL TEXTBOOK COMPANY

SCRANTON, PA.

1922

Printed in U. S. A.

INTERNATIONAL TEXTBOOK PRESS
Scranton, Pa.

95130

CONTENTS

NOTE.—This book is made up of separate parts, or sections, as indicated by their titles, and the page numbers of each usually begin with 1. In this list of contents the titles of the parts are given in the order in which they appear in the book, and under each title is a full synopsis of the subjects treated.

OPERATION OF DYNAMO-ELECTRIC MACHINERY (PART 1)

OPERATION OF DYNAMO-ELECTRIC MACHINERY (PART 2)

OPERATION OF DYNAMO-ELECTRIC MACHINERY

Serial 839A (PART 1) Edition 2

SELECTION AND INSTALLATION

SELECTION

1. A few general principles in regard to the selection of generators and motors apply to almost all cases. The construction of the machine should be first class in every respect. There should be evident solidity, each part being amply large, to insure durability, and as simple as possible; complicated parts are almost sure to cause trouble and expense. Machines in which careless workmanship, defective material, or poor finish are evident should be avoided. If there is danger of mechanical injury from foreign substances falling against the rotating parts, the machines should be provided with perforated doors or covers so arranged as to furnish the necessary mechanical protection and at the same time allow all possible ventilation. Electric machines for use in a damp atmosphere or one filled with dust or small flying particles of any kind should be entirely enclosed, dust- and moisture-proof, with suitable doors, or covers, for inspecting the working parts. This class includes motors for installation in mines, rolling mills, forge rooms, carbon works, cement works, etc.

The machine selected should be of ample size for the work required and its construction, both mechanically and electrically, should be such as to require the least possible

care and attention. The first cost of such a machine is not often of so great importance as is the cost of care and loss by breakdowns and repair bills.

2. The losses occurring in electrical machinery are mostly converted into heat, which raises the temperature of the surrounding parts. In the purchase of such machinery, it is important that the temperature rise, as well as the sparking and overload conditions, be fully specified. It is not best to specify to manufacturers of electrical machinery many of the details of construction. The conditions to be met should be clearly stated and the specifications strictly adhered to.

3. Finally, it is best always to deal with manufacturers of established reputation and to purchase machines so well standardized that duplicate repair parts can be quickly and easily obtained. Moreover, such concerns always keep in their employ competent engineers, who will give valuable advice as to an installation on which they are permitted to bid.

INSTALLATION

4. Location.—The location of a large generator or motor at a mine is generally determined by the location of the motive power and the work to be done. Aside from these considerations, however, the machine should be located in a clean, dry, cool place, protected from the dropping of water from steam and water pipes or from the roof. The location should afford, when practicable, a free circulation of air across the machine from windows or doors on opposite sides, but the air must be free from dust.

A space surrounding the machine, especially around the commutator and brushes, should be clean and free from all obstructions. If the machine is controlled from a switchboard, the operator should be able to reach the board without going through a belt or over other obstructions. Dust from the street is injurious to the commutator, bearings, and general insulation of electrical machines, but dust from a

coal pile or any kind of grinding or turning machine is even more so, because it is often more adhesive, or sharper and more gritty; therefore, the dynamo should be protected from the dust incidental to coal handling, and no emery wheels, grinders, speed lathes, etc. should be allowed in the dynamo room.

5. **Foundations.**—Every machine of 25 horsepower, or more, should be provided with a substantial foundation. In order to avoid communicating to the building the vibrations incidental to the running of the machine this foundation should, if possible, be independent of the floor and walls of the building in which it is installed. If several machines are to be installed in the same room, it will be best to have the whole floor space concreted and covered over with a layer of cement or a wood floor; but for a single machine it will be sufficient to make the foundation slightly larger than its floor area. In any case, stonework, solid brickwork, or concrete is the best foundation, but where these are impracticable, a substantial wooden frame construction can be used. When a concrete or brick foundation is used, it is customary to cap this with a hardwood frame, coated with a high-grade insulating compound of some sort; the layer of wood serves not only to insulate the metal frame of the machine from the ground, but it acts to cushion the blows and lessen the vibration due to the machine.

Insurance underwriters have established certain rules, known as the **National Code Rules,** for installing electrical machinery, wires, etc. to which all such installations must conform before the buildings containing them are insurable against loss by fire. Installations in and around mines seldom need to conform to these rules, because most mining companies assume their own fire risks. One of the National Code Rules requires that the frames of generators and motors be thoroughly insulated from ground wherever feasible. This is the usual practice in installing generators at mine power stations, the wood base frame furnishing the necessary insulation. The motors used in the mines cannot,

however, be so well insulated; and in any case where it is not feasible to thoroughly insulate the frame it should be permanently and effectively grounded, so that no one standing on the ground and touching the frame may under any condition receive a shock.

No rule in regard to the depth of the foundation can be given to cover all cases, as the subsoil is different in different places. In one section, bed rock will be found a few feet below the surface, while in another section it will be necessary to drive piles to support the foundations for the heavier machines. Fig. 1 shows a style of foundation very

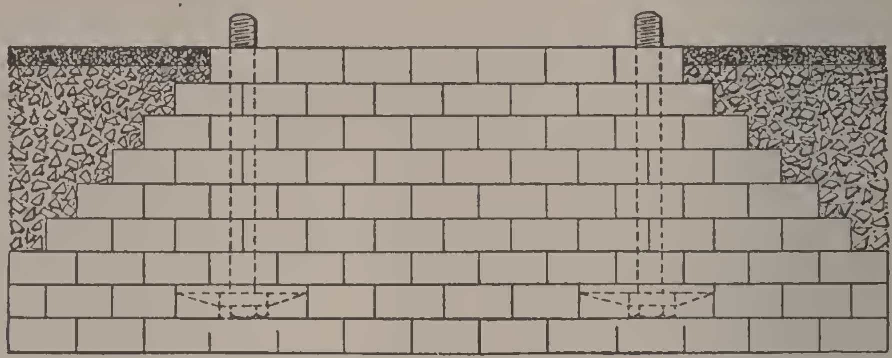


FIG. 1

much used; it is made of brick laid in mortar composed of one part of the best cement to two parts of good sharp sand. The sides of the excavation are filled in afterwards with a mixture of broken stone and cement, which is surfaced with a thin layer of pure cement. The masonry is built around the anchor bolts, which serve to hold the machine in place.

If the machine is belt-driven, means should be provided for tightening or slacking the belt. This is usually accomplished by mounting the machine on rails or on a subbase and moving it by means of a ratchet lever and screw, as shown in Fig. 2. The foundation should in every case be so disposed that the distance between the centers of the driving and driven shafts will allow one side of the belt to run looser than the other. This distance should be at least four times the diameter of the larger pulley. The loose side of the belt should be on top, the driving side below, as this will increase the arc of contact and the driving power of the belt.

6. Erection.—Small machines are usually shipped complete and ready to run, so that it is only necessary to set them in place, line them up, and put on the pulley. Large machines cannot be shipped with safety in an assembled condition, and are, therefore, dismounted and the parts marked and packed in separate parcels. The assembling of the parts should not be undertaken by one wholly unfamiliar

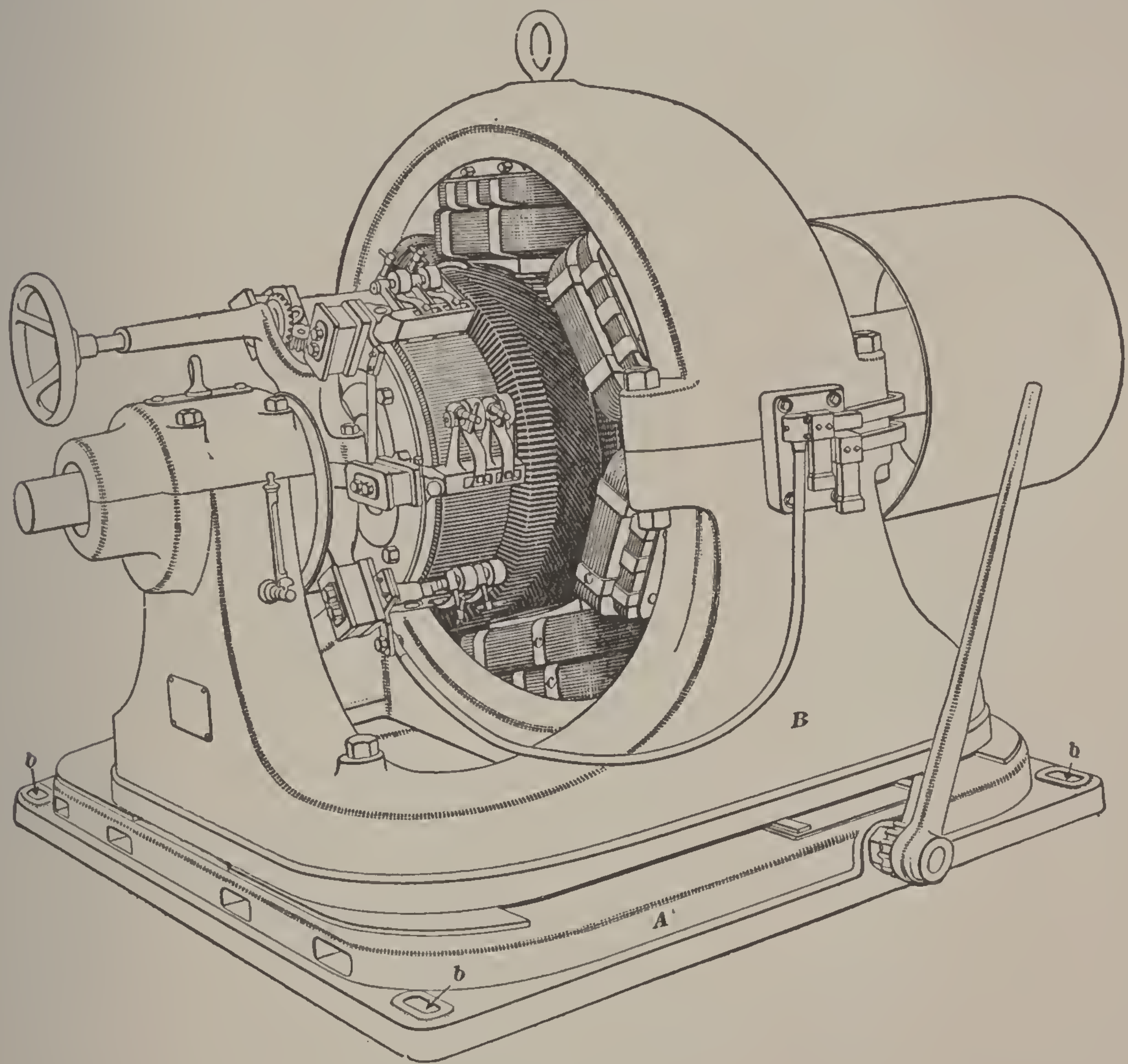


FIG. 2

with such work, and even an expert must follow closely the blueprints and the marks on the parts.

7. Wherever machinery is installed, the apparatus necessary for handling the separate parts and for assembling the machine or taking it apart should always be available. If the installation is not of sufficient size to warrant the purchase of an overhead crane, a chain hoist may be made to serve the purpose. If the overhead timbers are not strong

enough to support the heaviest weight, large trusses should be used. In any case be sure that the roof girders, cross-pieces, or trusses, as the case may be, as well as the hoisting apparatus, have ample strength for the work in hand.

Definite instructions for setting up the machine usually accompany each instalment or at least will be supplied, on request, by the manufacturers. Unless the plant is a small one or the location so far away as to make it impractical, the manufacturers will usually supply an experienced man to superintend the installation. A few general suggestions may, however, be made; and, in order to be specific, let it be supposed that the six-pole, belt-driven, Westinghouse railway generator shown in Fig. 2 is to be assembled.

8. The bedplate *A* and the lower half of the frame *B* are first worked into position, taking care in so doing not to disturb any part of the foundation. The lower field coils *c*, *c* are then put in place, taking particular care to assemble and connect according to markings on the coils. Hoist the armature over its final position, but, before lowering it into place, see that the journals are wiped clean, that they are free from any bruises or scratches, and are covered with a thin film of oil. Slip the bearings over the ends of the shaft, following markings, if there are any, and lifting the oil rings so they will not be jammed or sprung. Wipe all dirt, sediment, chippings, etc. out of the oil wells, lower the armature into place, and turn it a few times by hand to see that there is plenty of end play and that the oil rings turn properly. Fill the bearings with the best grade of thin lubricating oil but do not allow the oil to overflow, or oil throwing will result when the machine is started.

By using a spirit level on the shaft, see that the machine is level, raising one side or the other, as is necessary, by placing split washers, or shims, of thin metal under the bedplate around the anchor bolts. Put the remaining field coils in the upper half of the field frame and hoist it into position. All joints in the magnetic circuit, for example, between the two halves of the field frame and between the pole cores

and the frame, should be perfectly clean and coated with a thin layer of oil before being clamped together. These joints must fit perfectly and be thoroughly clamped. Now put on the pulley and line it up with the driving pulley to which it is to be belted. To do this, it may be necessary to turn the whole machine a trifle. Provision for doing this has been made by the slotted holes *b*, *b* in the corners of the bedplate. Lastly put on the brush-holder yoke, brush holders, and other fittings, and make all connections.

9. Too much caution cannot be used in handling such machinery, to see that it is not injured. A slight bruise or scratch on a journal or bearing or a bruised oil ring may result in a great deal of annoyance and possibly expense.

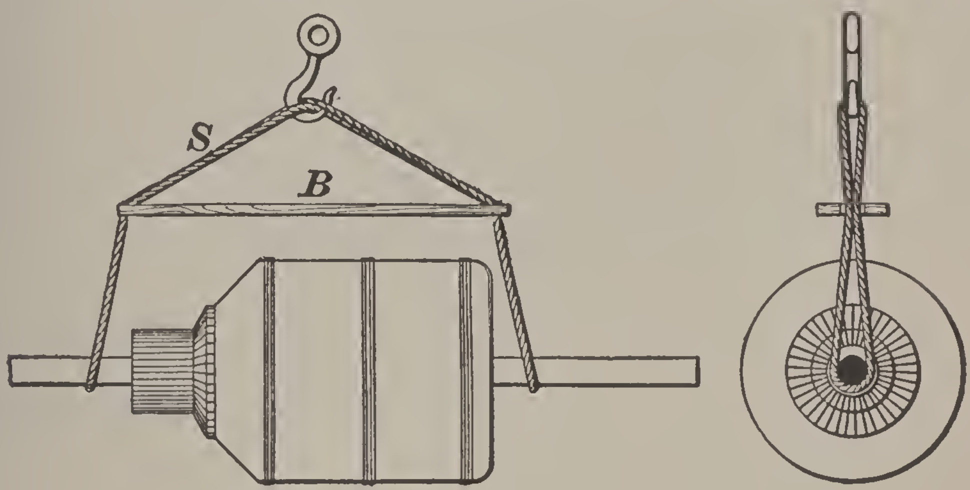


FIG. 3

Especial caution is needed in handling the field coils and the armature. It is imperative that these be not bruised or the insulation abraded in any way. The commutator is very sensitive to pressure or blows and should be shielded from them in every way possible. A very common way of hoisting an armature is shown in Fig. 3. The General Electric Company recommends for one line of generators an armature sling such as shown in Fig. 4; the rope makes two or more turns about the commutator, no two turns crossing each other. The pressure is thereby distributed all around the commutator. Knots should be tied in the sling to prevent the spreader from sliding down against the flange or end connections. This method may be convenient at times as it leaves the bearing free. It should, however, be avoided

unless the manufacturer of the machine being installed consents to its use. Lighter armatures may be handled as shown in Fig. 5. An armature must not be rolled or even

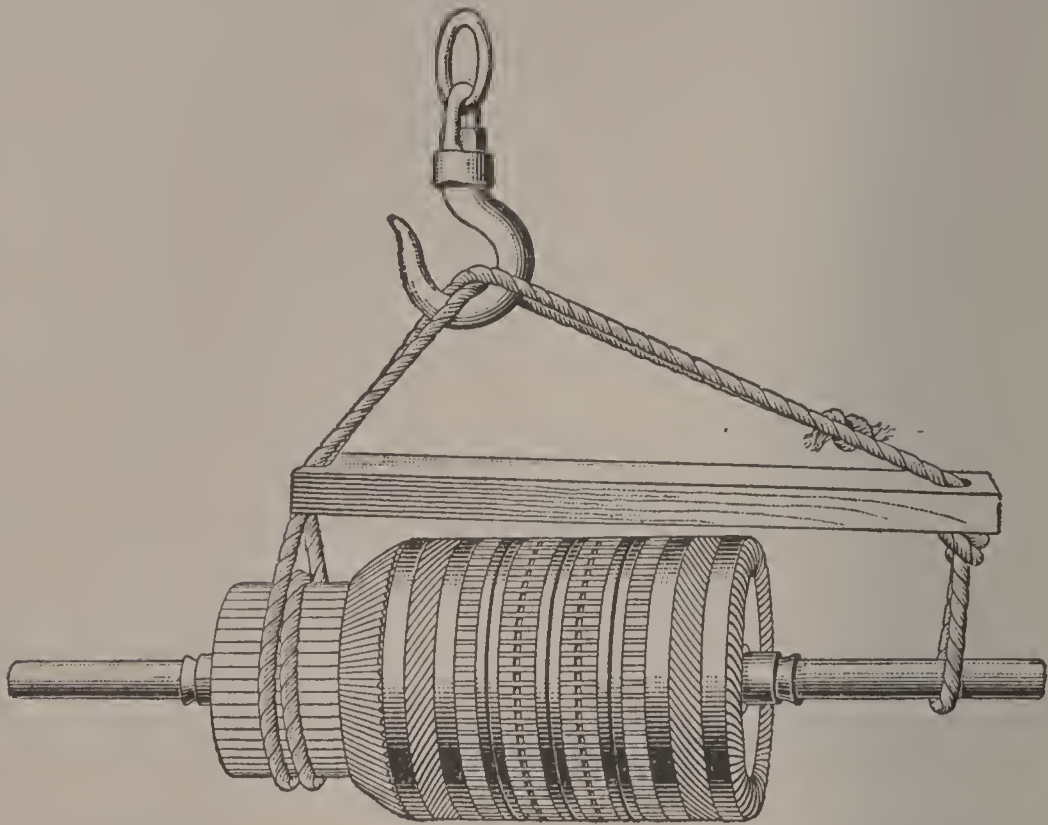


FIG. 4

laid on the floor where anything might possibly puncture the insulation or break a band wire, but must be supported by

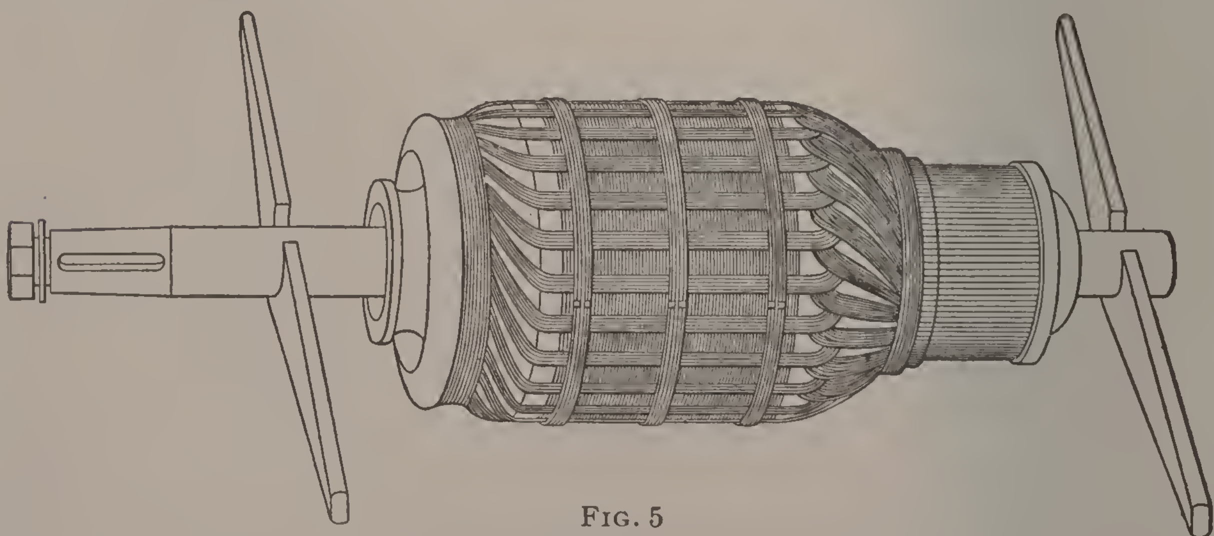


FIG. 5

trusses under the shaft, or, if it must be laid on the floor, it must be protected by padding.

10. Starting a Generator.—Care must be taken to have the machine in perfect order mechanically before starting it. Turn the armature slowly by hand to see that it does not rub or bind at any point. Put on the belt, with the minimum

distance between pulleys. See that all loose articles are removed from the machine. A good rule is never to allow a loose article of any kind to be placed on any portion of a generator. Start the machine up slowly and see that the oil rings rotate. When everything seems to be running smoothly and easily and without undue noise or vibration, gradually bring the machine up to speed and allow it to pick up its field. Tighten the belt until it runs steadily and without flopping and allow the machine to run several hours without load. If the windings have been exposed to dampness, it will be well to run at slow speed and a reduced voltage for a time, thus allowing the passage of sufficient current to dry out the moisture. After everything is in perfect order and the windings are thoroughly dried out, the speed and the load may be gradually increased until the desired capacity is reached.

11. The Belt.—The generator belt should be endless; that is, it should have a cemented joint in preference to a laced joint, which may produce vibration and cause trouble. Any person who has approached a large rapidly moving leather belt may have noticed the peculiar sensation that accompanies slight electric shocks. Unless means are provided to remove the static, or frictional, electricity that sometimes accumulates on large generator belts, the charge may become so heavy that it will jump through the air to the windings, puncturing the insulation and escaping to ground. The shocks from the frictional electricity on the belt may also sometimes be very disagreeable to the attendants. To prevent this accumulation of static charge, either the frame of the machine should be grounded or a metallic comb connected to earth should be so placed that the belt will run near the teeth and the charge will escape through the comb to earth. If the frame of the machine is insulated, as explained in Art. 5, a sufficient ground for the escape of the static charge but not sufficient to affect the frame insulation can be made by charring with a red-hot iron a fine line from a foundation bolt head along the wooden subbase to one of the bolts fastening the generator base.

OPERATION OF DIRECT-CURRENT GENERATORS

12. Dynamo-electric machines and all devices connected with their operation or regulation should be kept scrupulously clean. No copper or carbon dust, dirt, grease, or oil should be allowed to remain on any part of the machine. If compressed air is available, a jet of air can be used at frequent intervals to blow all loose dust out of the commutators, armatures, field coils, etc. If this cannot be done, use a good hand bellows. Not only the machines themselves but all their surroundings should be kept perfectly clean and free from rubbish or litter. The appearance of the generator room, as well as that of the machines, indicates the alertness of the attendants and the probable attention given the whole plant. Continual watchfulness is necessary to discover any possible defect before it has developed sufficiently to cause serious trouble. It is well to follow a definite system of inspecting and caring for electrical machinery. Each part should be systematically examined, and cleaned or repaired, if necessary, at regular intervals. If this is done, there will be less chance of overlooking or forgetting anything, and expensive delays or repairs may be avoided.

INDIVIDUAL PARTS OF MACHINES—THEIR DEFECTS AND REMEDIES

BRUSHES AND BRUSH HOLDERS

13. On direct-current machines, the brushes and commutator require, perhaps, more attention than all the other parts of the machine. Brushes are of two kinds: *radial* and *tangential*. **Radial brushes,** Fig. 6 (*a*), point straight toward the center of the commutator. **Tangential brushes,**

Fig. 6 (*b*), frequently made of copper, are found, as a rule, only on low-voltage high-current machines. Radial brushes are nearly always made of carbon and are always used on machines designed to rotate in either direction. The brushes should be so placed that with a slight end play of the armature the whole commutator surface will be utilized.

The pressure with which a brush should bear on the commutator depends on the material and condition of the commutator and the material of the brush itself. A copper brush does not, as a rule, require as much pressure as a carbon brush, and soft carbon will run with less pressure than hard carbon. Good practice is from $1\frac{1}{2}$ to 2 pounds per square inch. Pressures greater than 2 pounds per square inch are seldom necessary except where there is excessive vibration, as on railway motors. Increasing the pressure beyond what is necessary to maintain good contact only results in increasing the friction, with consequent heating and wear.

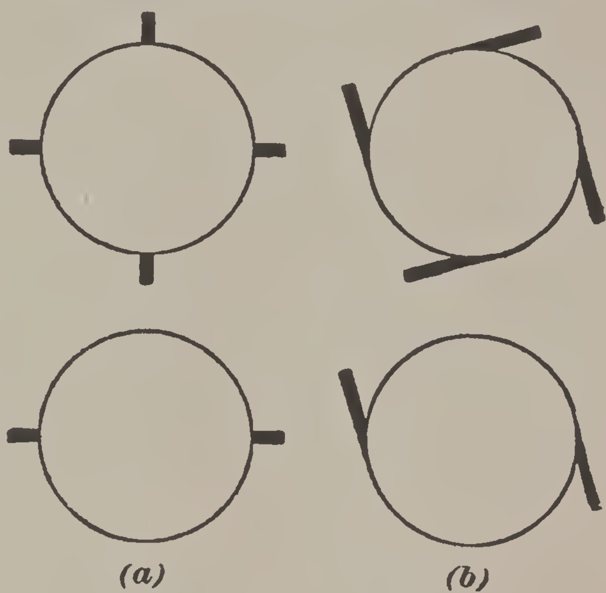


FIG. 6

14. Carbon brushes are made in several grades of hardness, adapted to different conditions of working and different kinds of commutators. High-voltage machines usually require harder carbons than low-voltage machines. There are so many conditions affecting commutators that it is very difficult to specify the grade of carbon most suitable to a particular machine. The carbon must not be so hard as to scratch the commutator nor so soft as to cover it with smut. Harder carbons are generally used on electric-locomotive and electric-car motors than for stationary work.

Carbon brushes may be given a good bearing surface on the commutator by sliding a piece of fine sandpaper back and

forth between the brush and the commutator, with the rough side next to the brush. Do not use emery paper on the brushes or the commutator, as emery is a conductor and may cause short circuits between adjacent commutator bars. Moreover, particles of emery sticking to the face of the brush, being more gritty than sand, will scratch the commutator.

15. Examine the brushes frequently when the machine is in operation to see that they have full bearing surface and that the surface is smooth and glossy. If the surface is raw, grayish in color, rough, and gritty, or if it is covered with particles or streaks of copper, something is wrong. Sometimes conditions can be improved by changing the brush lead, that is, shifting the brushes, and often considerable relief can be had by boiling the brushes in vaseline. To do this, place the brushes in a vessel with sufficient melted vaseline to cover them and boil for about one hour, after which remove the brushes and wipe them dry. If there is time let them stand in an oven or other warm place for a few hours and wipe off all surplus grease before replacing them in the holders.

16. **Metallic brushes** are made of strips of copper, bundles of copper wires, or, more frequently, copper gauze folded into shape and stitched. Those made of strips or wires are very liable to have the edges or ends of the laminæ fused together by sparking, forming hard points that cut the commutator. Whenever this occurs they should be taken out and the ends trimmed off. To get them to the proper level, so that they will rest evenly on the commutator at the proper angle, it is customary to use a filing jig, as shown in Fig. 7. This consists of a block of steel with a hole through it the size of the brush, and with one end beveled off to the proper angle and hardened. The brush is placed in the jig with the end

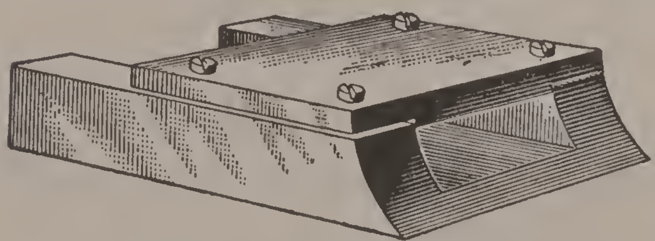


Fig. 7

projecting a little from the beveled face, and clamped in position. The end of the brush may then be filed or ground down flush with the face of the jig, thus giving it the correct bevel.

Metallic brushes should not be allowed to become filled with oil or dirt; if they get in this condition, they may be readily cleaned with benzine or kerosene.

17. Brush Holders.—The moving parts of the brush holders should be as light as is consistent with strength, and there should be no stiffness or rigidity to prevent the brush from closely following any unevenness in the commutator. If carbon brushes are used, the brush, as it wears off, should move toward the center of the commutator and the pressure of the brush spring should remain practically constant until the brush is worn out. To prevent a tendency to *chatter*, or jump from the commutator, the brush holders should be set as near the commutator as possible. These points regarding brush holders are determined by the manufacturer but will guide in selecting a machine.

THE COMMUTATOR

18. The **commutator** is the most sensitive part of a machine, and its faults are liable to develop more quickly than those of any other part. When a commutator is in the best possible condition, it becomes a dark-chocolate color, is smooth, or glazed, to the touch, and causes the brushes, if of carbon, to emit a characteristic, squeaky noise when the machine is turning slowly. Oil should be used very sparingly, if at all, on a commutator; to lubricate it, put a film of vaseline on a canvas cloth, fold the cloth once, and let the commutator get only what oil goes through the pores. Too much oil or grease will cause arcing or flashing at the brushes and black rings will form around the commutator. These should be wiped off with a clean cloth. Never use waste to wipe the commutator or brushes, and the cloth used should be as free as possible from lint.

Some of the more common faults likely to develop in a commutator are roughness, eccentricity, and high or low bars. Any of these will cause sparking, flashing, or heating and unless attended to may soon render the machine incapable of further operation.

19. Roughness of the commutator may be due to overloads, to improper setting of the brushes, to poor workmanship or material, or to defective design. For occasional slight roughness, due to either of the first two causes, sandpaper may be used; but if the condition keeps recurring and seems to be due to either of the last two causes or to some other cause not readily ascertained, some more permanent remedy must be used.

Before using sandpaper remove the brushes or fasten them back where they will be out of the way. Hold the sandpaper on the rotating commutator with a segment of wood having the same radius as the commutator. Use No. 2 sandpaper at first and finish with No. 0. For a final polish, reverse the paper and hold the smooth side next to the commutator for a moment. Blow all dust out of the machine as soon as the operation is completed.

20. Stoning.—Frequently, a commutator that appears very rough may be placed in a satisfactory condition by a process called **stoning.** A block of sandstone 4 inches square and 8 inches long can be placed in a wooden holder of convenient shape and size and one of the long surfaces made to fit the curvature of the commutator. Grinding a commutator with a stone made in this way is preferable to using sandpaper, for the stone will not dip into low places but will grind the high bars only. If the stone is coarse, it may be desirable to finish the commutator with fine sandpaper. The stone will not reduce the diameter of the commutator, or the radial *wearing depth* of the bars so much as a turning tool.

21. Eccentricity.—If a commutator is not properly baked during construction or is not screwed down after it is baked, it is liable to bulge out in the course of time under

the action of the heat due to its normal load and the action of centrifugal force, or it may develop loose bars. In the case of the bulging of one side, sandpaper will not do any good. The best thing to do with such a commutator is to take it off, bake it so as to loosen the insulation, tighten it up well, and turn it off in the lathe. For ordinary unevenness of surface of large commutators due to wear, it is customary to set up a tool post and a slide rest on the bedplate of the machine itself and turn off the commutator while in position. Commutator turning tools that may be readily attached to almost any large generator or motor are supplied by many leading manufacturers of electrical machinery.

22. High or Low Bars.—If when a commutator is rotated slowly a sharp metallic click is heard as many times per revolution as there are brush holders, and a slight jumping of a brush is noticed every time the click is heard, there is probably one or more high bars. If it is a high bar and if it is tight in the commutator, the material in the bar is probably too hard; the bar may be dressed down with a file while the armature is standing still. A low bar may be due to soft material, to bad sparking caused by a defect in the armature winding, to a careless blow, or the bar may be loose. If due to any of the first three causes, the armature surface should be turned down in a lathe or with a commutator turning tool to the level of the low bar. If due to the second cause, the defect in the winding should also be found and removed. A loose bar, either high or low, will necessitate a thorough repair job. After turning a commutator always finish with No. 0 sandpaper as directed in Art. **19.** Inspect the surface closely to see that no burrs bridging across the mica have been left by the tool.

23. The most serious condition is to have an armature or a commutator that is defective in design or that contains defective material or workmanship. If the design is a poor one, it may be very difficult or even impossible to keep the commutator in good condition. If the mica is too soft, it will pit out between the bars, leaving a trough to fill up with

carbon dust and thus short-circuit the neighboring armature coils. If the mica bodies are too hard or too thick, the bars will wear in ruts and require frequent turning down.

THE ARMATURE

24. Heating.—An armature should run without excessive heating; if it heats so as to smoke or give off an odor, the machine should be shut down at once and the cause of the heating should be located and removed. The odor of overheated insulation is very peculiar and easily recognizable, especially after having once been experienced. The heating may be caused by damp insulation—a condition that, as a rule, is shown by steaming, but which can be determined by measuring the insulation resistance to the shaft with a voltmeter. If low resistance is indicated, the armature should be baked, either in an oven or by means of a current passed through it in series with a resistance which may consist of a number of lamps, known as a *lamp bank*, or as directed in Art. **10.** The baking current should not exceed the full-load current of the machine. If, while the machine is at rest, a current for baking purposes be sent through the armature from an external source, be sure that the series-field, if the machine has one, is not included in the circuit, and that the shunt field is broken; for if either field is on, the machine may start up as a motor.

25. Short Circuits.—If, instead of the whole armature running hot, the heat is confined to one or two coils, there is probably a short circuit either in a coil or between the two commutator bars to which the ends of the coil connect. If a short-circuited coil is run in a fully excited field, it will soon burn out. A short circuit of this kind can be readily detected by holding an iron nail or a pocket knife near the head of the armature while it is running in a field; any existing short circuits in the coils or commutator will cause the piece of metal to vibrate very perceptibly each time the defect passes underneath. If the trouble is confined to one or two coils it can frequently be located by stopping the machine after

running a few moments and feeling the armature all over for the hot coil.

If one or more coil connections are reversed on one side of a generator armature, that side will generate less electromotive force than the other, and hence, will receive current from the other side; that is, a current will flow through the armature coils that does not flow through the external circuit. This current is useless and heats the machine unnecessarily. It the same mistake is made in connecting a motor armature, the side having the reversed connections will generate less counter electromotive force than the other side and will therefore receive more than its share of the current flowing through the motor, making this side overheat.

26. A flying cross in an armature is a defect caused by a loose or broken wire with poor insulation; when the armature is standing still or even when it is rotating much below its standard speed, the wire may remain so nearly in place that the defect cannot be noticed; but when full speed is attained, centrifugal force throws the wire out of place and into contact with other wires or with the core or framework of the machine, causing sometimes severe sparking or flashing. Such a defect is often very hard to find; some of the tests given in Art. **25** may assist in locating it, or it may be necessary to give the whole armature winding a minute inspection.

27. Overloaded Armatures.—One of the most common causes of general trouble and heating in an armature is **overload**; this may be due to ignorance or neglect or to an error in the instrument that measures the load. There is a great tendency on the part of owners to gradually increase the load on a machine until it may be doing much more than the work for which it was designed. By adding lamps one or two at a time it is an easy matter to unwittingly overload a generator. Or in the case of a motor, small devices may be added, one at a time, until an overload is the result. Ammeters sometimes get out of order, read incorrectly, or stick, and thus do not indicate the full load of the machine.

FIELD-COIL DEFECTS

28. Open Circuits.—Among **field-coil defects** are *open circuits*, *short circuits*, *grounds*, and *wrong connections*.

An **open circuit,** or a break, occurring in the field circuit of a generator or a motor when the machine is idle, will usually be discovered on attempting to start up, before any further injury has resulted. If the break occurs while the machine is in service, the field magnetism will be lost, with results more or less disastrous, depending on the style of winding, the work the machine is doing, and whether it is operating alone or with other machines. For example, if the break occurs in the shunt field winding of a shunt- or a compound-wound generator, operating alone, the machine will merely cease to generate; if operating in parallel with other generators, as explained later, the other machines will be short-circuited through its armature with the possible burning out of some or all of the generator armatures on the circuit. A shunt motor will cease to generate counter electromotive force, and its armature will become a short circuit across the line and will be burned out unless the armature circuit is opened almost immediately. Application of the principles governing the generation of an electromotive force will enable one to determine the result of a break in the field circuit under conditions other than those given above.

29. Short Circuits.—The effect of a short circuit in a field coil depends on the kind of machine and the method of field connection. If the defect occurs in a shunt field, there will be an increased field current, and but very little change in the speed of a motor or in the electromotive force of a generator. If a series-field is short-circuited, the effect in a generator is to reduce the electromotive force and in a motor to increase the speed; hence, if the electromotive force of a generator becomes too low or the speed of a series- or a compound-wound generator becomes too high and the change cannot be otherwise accounted for, it is probable that the series-field has become short-circuited.

Short circuits may be caused by carelessness in winding or in handling, by defective insulation, or by moisture. By far the larger part of such defects are probably due to moisture absorbed by the insulating materials when the machines are idle for some time, especially if they are in a damp place. This moisture should be baked out either in an oven or by allowing a small current to flow through the coils for some time, increasing gradually to the normal current as the coils become dried. If very moist, the coils should be baked in an oven before sending a current through them.

30. Grounds, or Connections, Between Windings and the Field Frame.—In circuits, neither side of which is permanently grounded, an accidental grounding of the windings will produce no further immediate injury to the machine, provided that the ground be removed at once; but if it be allowed to remain until a second one occurs the two will have the effect of a short circuit. On electric-railway circuits, however, where one terminal of the generator is permanently grounded to the rails, a single ground on the windings will have the effect of a short circuit.

31. Wrong Connections.—One or more field coils may be connected so that the current flows through them in the wrong direction, or the series and shunt coils of a compound-wound machine may be connected **differentially,** that is, so that they oppose each other in effect, when they were intended to be connected **cumulatively,** that is, so that they would assist each other in magnetizing the fields. It is a good plan, when connecting up a machine, to try the poles with a compass when the fields are excited, to see that the north and south poles alternate, and the series and shunt fields, if both are used, are connected in the right direction with respect to each other.

REASONS FOR A GENERATOR FAILING TO GENERATE

32. Among the causes for a generator failing to generate may be given, loss of residual magnetism; wrong connections of field or armature; open circuits or poor connections; short circuits; low speed; magnetic-circuit defects, that may consist of bad flaws, or blowholes, in the field casting or poor magnetic joints; wrong position of the brushes, etc. Some of these causes may result in a decreased voltage instead of a complete failure to generate.

33. Loss of Residual Magnetism.—Of all the causes that may make a generator fail to generate, the loss of residual magnetism, or **charge,** is one of the most troublesome. As a rule, generators leaving the factory retain enough residual magnetism to start on, but there are several ways in which they can lose it. Some generators never lose their charge, while others are continually doing so.

34. When a generator has lost its charge, the pole pieces have little or no attraction for a piece of soft iron. Series-generators seldom lose their charge so entirely that they fail to pick up a field on short circuit. When a compound-wound generator refuses to pick up a field with its shunt winding, it can often be made to pick up by disconnecting the shunt coils and short-circuiting the machine through a small fuse. Machines can in some cases be made to pick up a field by simply rocking the brushes back from their neutral position.

If these expedients fail to produce the desired result, the fields must be recharged from an outside source. If the generator runs in multiple with other generators, it is only necessary to lift the brushes or disconnect one of the brush-holder cables on the dead machine and throw in the main-line switch, the same as if the machine were going into service with the others. The fields will then take a charge from the line and their polarity will be correct. If the generator does not run in multiple with another and there is a generator within wiring distance, disconnect the shunt field of the dead generator and connect it to the live circuit. If there are

absolutely no other means available for charging, several ordinary battery cells may be used. As a last resource, when all other available sources fail, connect the fields so as to obtain the least possible resistance, put them in series with the armature through a small fuse, and speed the armature considerably above the normal rate. Very often a generator, instead of losing its residual magnetism, will acquire one of a reversed polarity, due, perhaps, to the same causes exercised to a greater degree. In this case, the generator will build up with the polarity of the brushes reversed. In some cases this would do no harm, but in most cases it is essential that the brush polarity be always the same and if the generator begins to build up wrongly it is best to stop it at once and ascertain the cause. If it is found that the residual magnetism is reversed, an external electromotive force should be applied, as before indicated, to restore the fields to their proper direction.

35. Wrong Connection of Field or Armature.—In the process of building up the field of a generator, it is essential that the very slight electromotive force due to the armature conductors cutting the residual magnetic field, shall send current around the field coils in such a direction as to *add to* the residual magnetism. If the reverse were true, all the magnetism would be killed and the generator would fail to generate. It follows, then, that if, after a generator has been left charged in one direction, its field or armature leads are reversed, the machine will not pick up; and, if it is run long with these wrong connections, the residual magnetism will be completely lost and the machine will fail to pick up, even when the connections are made right again, until the fields have been recharged.

36. Again, one or more field coils may be incorrectly put on, or connected so that they oppose one another. On a compound-wound generator, the reversal of a shunt-field coil will generally keep the generator from picking up on open circuit, unless the generator has more than four coils; the more coils it has, the less effect will the reversal of a single

coil have. The reversal of a series-coil is not felt until an attempt is made to load the machine; the voltage will not come up to where it should for a given load, and the brushes are apt to spark on account of the weakened field.

37. Open Circuits or Poor Connections.—A shunt or compound-wound generator will not pick up if the shunt-field circuit is open; the open circuit may be in the field itself, in the field rheostat, or in some of the wires or connections in the circuit. A careful inspection will generally disclose any fault that may exist in a wire or connection. To find out if the rheostat is at fault, short-circuit it with a piece of copper wire; if the machine generates with the rheostat cut out, the fault is in the rheostat. A field circuit is sometimes held open by a defective field switch that is apparently all right; repeated burning may have oxidized the tip of the switch blade and formed on it a non-conducting blister, which prevents the jaws of the switch from coming into electrical contact with the blades. Another trivial but common cause of open circuits is the blowing of fuses.

An open circuit in an armature will interfere with the proper generation of electromotive force, but such a fault, as a rule, announces its own occurrence and location in a very emphatic manner. There will be severe sparking and the commutator bars to which the open coil is connected will be badly burned in a short time.

Before attributing the failure to generate to any of the foregoing open-circuit causes, see that the brushes are on the commutator, the field switch closed, and the greater part of the field rheostat cut out. The electromotive force generated when a machine is first started is very small, because the residual magnetism is weak. It may not require a complete open circuit in a field to prevent a machine picking up. A bad contact that might not interfere with the working of the machine when it is up to full voltage may be sufficient to prevent its picking up when first started. A loose shunt wire in a binding post, or a dirty commutator may introduce sufficient resistance to prevent the

machine from operating. Trouble is very often experienced in making machines with carbon brushes pick up, especially if the brushes or commutator are at all greasy. If such is the case, clean the commutator thoroughly, wipe the ends of the brushes with benzine, and see that they make a good contact with the commutator surface.

38. Short Circuits.—A short circuit occurring on the main line of a shunt generator while the machine is running will cause it to lose its field; therefore, the machine will not pick up if its line is short-circuited. A short circuit on the line of a series-wound or a compound-wound generator increases its ability to pick up, because the fault is in series with the series-coils and a large current passes through them. A series-generator cannot pick up with its external circuit open, because no current can flow through its field coils. Either a series or a shunt generator may not pick up if its field is short-circuited. A compound-wound generator may not pick up on open circuit if the shunt field is short-circuited; if the series coils only are short-circuited, the machine will pick up with the main circuit open, but will not hold its voltage when the current begins to flow. In some cases, a shunt generator will not pick up on full load, as this realizes too nearly the condition of a short circuit; so that to be on the safe side it is best to let the machine build up its field before closing the line switch.

Short circuits within the generator itself generally give rise to indications that point out the location and nature of the fault. In any event, the first thing to find out is whether the fault is in the generator or out on the line; if the machine picks up its field when the line switch is opened, but fails to do so when it is closed, the trouble is on the line.

39. Low Speed.—A generator will not pick up its field when running below a certain speed, but with the field once established, the machine will hold it at a much lower speed than that required to pick it up. The speed at which a series-generator will pick up depends on the resistance of the external circuit.

40. Other Causes.—Defects in the magnetic circuit appear, if at all, when the machine is first assembled. Generators with defective field castings are, of course, not allowed to leave the factories of reputable makers. Defective magnetic joints may be due to carelessness in assembling. The correct position of the brushes, as found by the factory test, is usually marked in a conspicuous place on the generator frame near the brush-shifting device. In any case, this position should easily appear after a few trials, even if the mark cannot be found.

SPARKING AT THE COMMUTATOR

41. Probably the most troublesome and annoying feature in the operation of direct-current generators and motors is **sparking at the commutator.** The cause is not always apparent, but may usually be found among the following: Too much load; brushes improperly set; commutator rough or eccentric; high or low bars; sprung armature shaft; brushes making poor contact; dirty brushes or commutator; too high speed; low bearings; worn commutator; short-circuited or reversed armature coil; open-circuited armature; vibration; belt slipping; weak field; grounds.

42. An **overloaded armature** heats all over. The sparking may be lessened but not stopped by shifting the brushes ahead on a generator and back on a motor. If the machine is a motor, the speed will be low; if a generator, the voltage will be below the normal amount, unless the machine is heavily overcompounded.

Brushes may be improperly set in either of two ways: they may be the right distance apart but too far one way or the other as a whole; this can, of course, be remedied by shifting the rocker-arm back and forth until the neutral point is found. The brushes may, as a whole, be central on the commutator, but the spacing between adjacent holder studs be wrong. Count the commutator bars between adjacent sets of brush holders and adjust the spacing until the number of bars between each pair is the same.

43. Remedies for a **rough** or **eccentric commutator** were given in Arts. **19, 20,** and **21.** A **sprung shaft** has the same effect as an eccentric commutator; either will cause the brushes to jump from the commutator and sparking will result. Before turning the commutator for eccentricity be sure that the trouble is not due to a sprung shaft.

A **high** or **low bar** in a rotating commutator causes the brush to jump from the commutator, and this gives rise to sparking.

A **sprung armature shaft** causes the commutator to wabble, producing very much the same symptoms as an eccentric commutator.

44. The **brushes may make poor contact** due, to a brush being stuck in a holder so that the spring does not force it down on to the commutator; to the temper being out of the spring; to the pressure of the spring not being brought to bear directly on the brush; to the brush not fitting the commutator surface, etc.

Dirty brushes or **commutator** may cause the brushes to make poor contact. Some carbon brushes contain paraffin placed in them for lubricating purposes. When the brushes are hot, the paraffin may run out too rapidly and cover the commutator with a greasy smut, which insulates it in spots. Copper brushes sometimes get clogged with oil, dust, and bits of lint or waste. Dirty commutators are usually the result of using too soft brushes, or too much oil, or frayed cloths or waste in cleaning.

45. **Too high speed** is apt to make a machine spark, because it affects the correct position of the brushes.

Worn bearings sometimes throw the armature far enough out of the center to distort the field and cause sparking.

A **badly worn commutator,** even if otherwise in good condition, seems inclined to spark in spite of everything that can be done. It may be because, as the bars wear down radially, they also become thinner and the brushes then span too many bars, in which case a thinner brush may

give relief; or it may be because the error in the angle of the holder increases with the distance from the commutator.

46. Either a short-circuited or a reversed armature coil will cause a local current that will increase the power required to run either a generator or a motor, even without any load. A motor will run with a jerky motion, especially noticeable at low speeds, and a generator will cause the needle of the voltmeter connected to its terminals to fluctuate. In either case, unless the cross that causes the trouble is removed, the coil will burn out.

By an **open-circuited armature** is meant a break in one of the armature wires or its connections. Excessive current may burn off one of the wires or a bruise of some kind may nick a wire so that the normal load, or perhaps less, burns it off. A commutator may become loose and break off one or more leads. Sometimes, on account of excessive heating, the armature throws solder and all the commutator connections become impaired; in such a case, while there may be no actual open circuits, there are poor contacts that result in making the commutator rough and black.

47. **Vibration** of a generator or a motor will cause constant sparking, even at very light loads. The vibration may be due to a poor foundation or to a poorly balanced armature; the remedy is to place the machine on a firmer foundation or to properly balance the armature.

A **slipping belt** will sometimes cause intermittent sparking, because it subjects the machine to unusual variations in speed.

48. Causes for **weak fields** have already been mentioned; viz., poor joints, either magnetic or electric, wrong connections, short circuits in series-fields, etc. A weak field magnetism is easily distorted by armature reaction until it may become impossible to shift the brushes to a point of sparkless commutation.

As in the case of field coils, a single **ground** on the armature windings of a railway generator, or any machine working on a permanently grounded circuit, will have the effect of a short circuit and will cause sparking and heating, as described

in Art. **30.** On completely insulated circuits, two grounds on the generator armature windings will cause a short circuit with the same effects.

49. The causes of sparking thus far mentioned are such as may be due to improper treatment or abuse after a machine has left the factory, and not necessarily the result of faulty design or construction. It sometimes happens, however, that notwithstanding a generator or motor receives only the best of care, it persists in sparking badly at full load or even less. This may be due to poor design, mechanically or electrically, something for which the attendant is not responsible, excepting possibly as the machine may be one of his selection.

50. A moderate amount of sparking at the commutator is not objectionable, but, if it becomes sufficient in amount or in duration to blacken or roughen the commutator bars, the cause should be located and removed if possible. Numerous small white sparks, evenly distributed along the edge of the brush and producing no distinguishable noise, usually work little injury. Larger sparks, appearing at irregular intervals along the edge of the brush, usually with a greenish hue and accompanied by a hissing sound, are more serious. Such sparks usually cling tenaciously to one point on the brush edge, and they are due to small particles of copper, torn loose from the commutator by excessive local heat and which cling to the brush surface. On stopping the machine after running a few hours with this kind of sparking, a furrow, or strip, will be found cut into the commutator all around the circumference under the spot where the spark appeared. Sparks due to incorrect position of the brushes, when load is changed, produce a vicious snapping sound, easily distinguished after having once been heard. A well-designed, modern, direct-current generator or motor, with the brushes in one position, should be sparkless from no load to full load and possibly to 25 per cent. overload. There should be no injurious sparking at 50 per cent. overload and many manufacturers guarantee their machines to stand even 100 per cent. overload, momentarily, without injury.

TESTING FOR FAULTS

51. Many of the defects that are liable to develop in dynamo-electric machines are apparent from a mere inspection. Other defects, such as short-circuited or open-circuited field coils or armature coils, must be located by making tests. For tests of this kind, the Weston or similar instruments are most convenient if they have the proper range for the work in hand. For measuring resistances, the *drop-of-potential method* is generally most easily applied. This method consists in sending a known current through the resistance and measuring the drop of potential between the terminals of the resistance from which the amount of resistance is calculated. For measuring a very low resistance as, for example, that of an armature coil, the voltmeter must be capable of reading low, say to thousandths of a volt. A millivoltmeter will be best suited to this work.

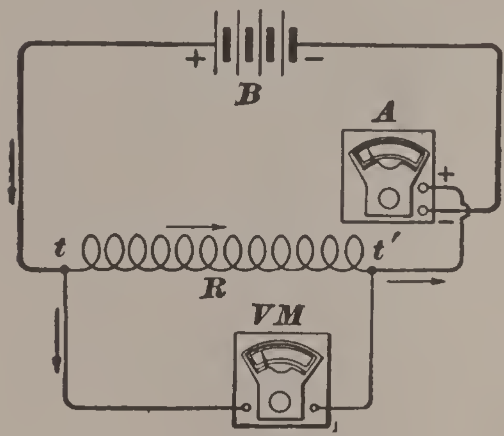


FIG. 8

52. The **drop-of-potential method** of measuring a resistance may be better understood by reference to Fig. 8, where it is desired to measure the resistance of coil R. An ammeter A is connected so that it will measure the current forced by a battery B, or any other source of electromotive force, through the coil; and a voltmeter VM, connected to the terminals t, t', measures the electric pressure across the coil, or the drop of potential in the coil. From Ohm's law, current $= \frac{\text{electromotive force}}{\text{resistance}}$, or resistance $= \frac{\text{electromotive force}}{\text{current}}$. For example, if the ammeter indicates 1.5 amperes and the voltmeter 9 volts, the resistance equals $9 \div 1.5 = 6$ ohms.

53. Open-Circuited Field Coils.—If a generator fails to pick up, and a voltmeter connected across the brushes shows a small deflection when the machine is running at full speed, the failure cannot be due to loss of residual

magnetism. A careful examination will reveal any defective or loose connections between the coils. Quite frequently, the wire becomes broken at the point where the leads leave the spool, while the insulation remains intact, so that the break does not show. This may be detected by bending the leads to and fro.

If the break, however, is inside the winding of one of the coils, it can be detected only by testing each coil separately to see whether its circuit is complete. To do this, connect the field directly across the circuit of another generator, if one is available, as in Fig. 9, where the field terminals are connected at *a*, *e* to wires coming from another machine in operation. If the field coils *1*, *2*, *3*, *4* were all perfect, a current would flow through them; but if one of them has a break in it, as at *B*, no current can flow. To locate the defective coil, the terminals of a voltmeter are touched to the terminals of the different coils until the defective one is indicated by a deflection of the voltmeter needle. The needle will in this case indicate drop of potential. When the terminals are touched to terminals *a*, *b*, of coil *1*, there will be no deflection of the needle because no current is flowing through coil *1*, hence there is no drop of potential in the coil. When the voltmeter terminals are touched to terminals *b*, *c* of the defective coil, as indicated by dotted lines, it is connected through coil *1* to the positive side of the circuit and through coils *3* and *4* to the negative side; hence, it will measure the full pressure of the circuit connected to *a*, *e* provided the other coils are perfect.

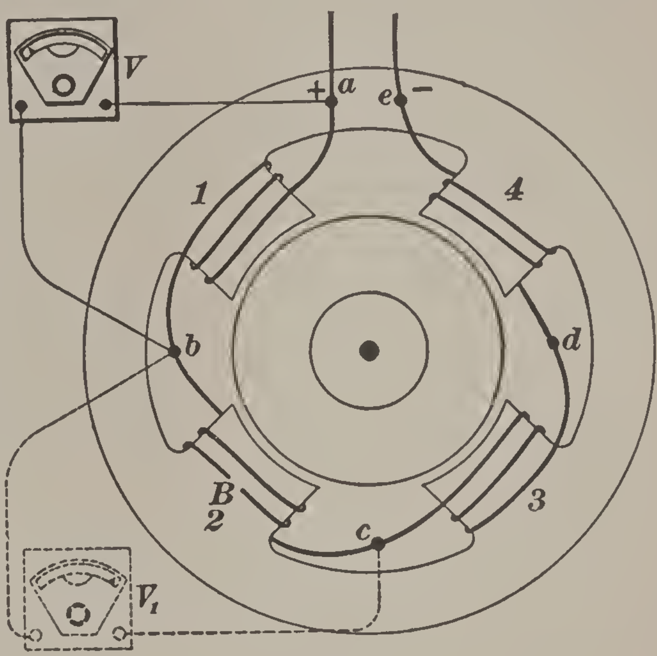


FIG. 9

If a generator circuit is not available for making the test illustrated in Fig. 9, a common battery and a bell in series,

or a magneto-electric bell such as ordinarily used for telephone signaling (called *magneto* for short), may be substituted for the voltmeter. It is evident that if connections are made at the terminals *a*, *b*, of coil *1*, or those of any other perfect coil, the bell will ring, but if made at *b*, *c*, or at the terminals of any other coil containing a break, there will be no ring.

54. Short-Circuited Field Coil.—If the windings of a field coil become short-circuited, either by its wires coming in contact with each other or by the insulation becoming carbonized, the defective coil will show a much lower resistance than it should. The drop of potential across each of the various field coils should be about the same, so that, if

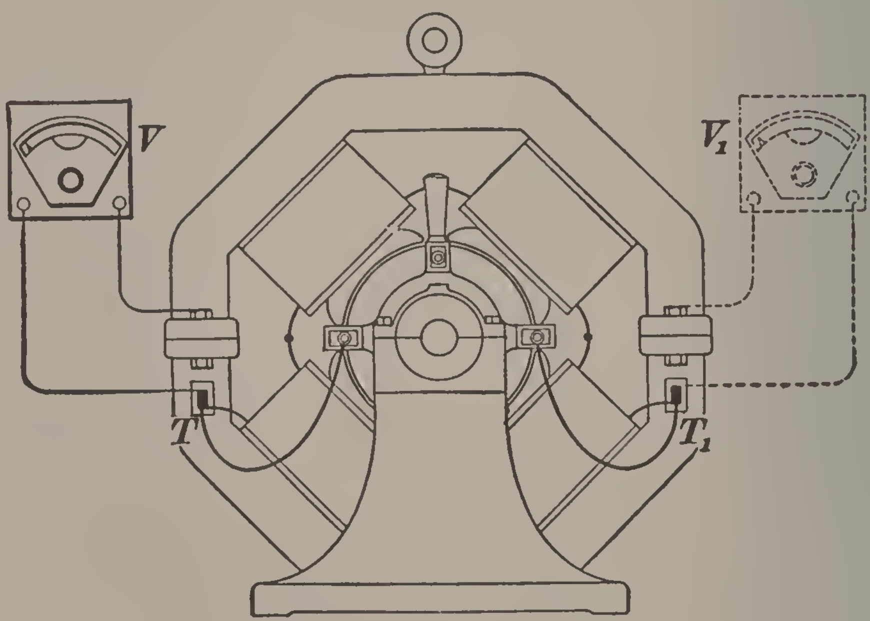


FIG. 10

one coil shows a much lower drop than the others, it indicates a short circuit of some kind. The short-circuited coil will usually run cooler and all the others warmer than normal.

55. Grounds Between Winding and Frame.—After a machine has thoroughly warmed up for the first time after being installed, and at frequent intervals thereafter, it should be tested for grounds. This may best be done with a good high-resistance voltmeter, as follows: While the machine is running, connect one terminal of the voltmeter to one terminal of the generator and the other terminal of the voltmeter to the frame of the machine, as shown in Fig. 10, where *T*

and T_1 are the terminals of the generator and V and V_1 two positions of the voltmeter, connected as described above.

If in either position the voltmeter is deflected, it indicates that the field winding is grounded; the greater the deflection, the nearer the ground to the other terminal; that is, a large deflection at V shows that the machine is grounded near the terminal T_1. If the needle shows a deflection in both positions, but seems to vibrate or tremble, the armature or commutator is probably grounded. If in either case the deflection does not amount to more than about one-twentieth the total electromotive force of the machine, the ground is not serious; but if the deflection is much more than this, the windings should be examined separately, the ground located, and, if possible, removed. Before making this ground test on a railway or other permanently grounded generator, the grounded terminal should be disconnected from the circuit.

56. Locating a Ground.—Fig. 11 illustrates a method of testing to locate a ground. The machine is shut down and the electric circuit broken into as many distinct portions as possible; that is, each field coil is disconnected from its neighbors and the generator terminals T, T_1 are disconnected from the external circuit. C, C_1 are terminals of a live circuit of about the same difference of potential as the

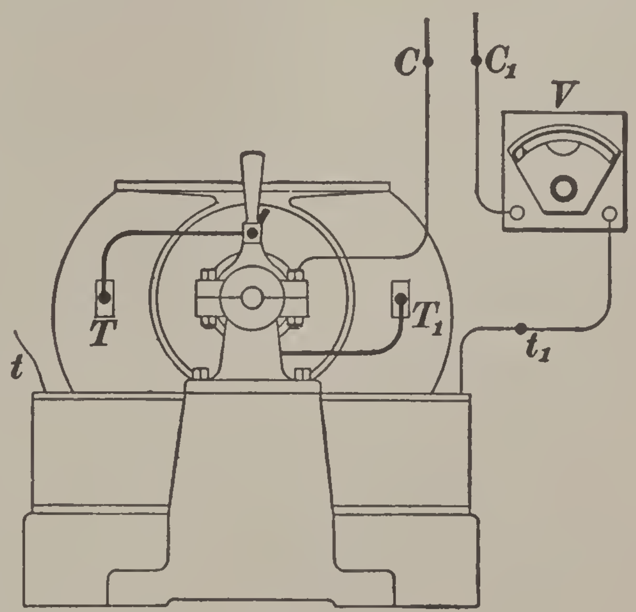


FIG. 11

normal voltage of the defective generator when running. One terminal C of the live circuit is connected to some bright surface on the frame (a bolt head in this case) where good contact can be had, and the other to a voltmeter V of sufficient capacity to measure the full electromotive force of circuit C C_1. The other voltmeter terminal is connected to successive field terminals t, t_1, etc. and if need be to the

machine terminals T, T_1, or to the commutator. In each case little or no deflection will be shown until connection is made to the defective portion of the circuit. In the figure, if the coil with terminal t_1 were grounded, the voltmeter would show a deflection. If the ground were complete, that is, a *dead ground*, the deflection would show the full voltage of the circuit $C C_1$.

57. Defects in the Armature.—Faults in the armature may best be located by what is known as the **bar-to-bar test,** connections for which are shown in Fig. 12. A current from an external circuit E is led through the armature by way of contacts $A B$, which may be clamped to the commutator. A variable resistance, represented by the lamp bank $L B$ should be used to regulate the strength of this current. A millivoltmeter G is connected, through the commutator bars $1, 2, 3$, etc., successively, to the individual coils N, W, K, S, etc., by means of a contact maker, or crab, C, which is provided with two properly spaced contact pieces. Suppose, in this case, that the generator has three defects, which are as follows: (1) There is a break in coil T, which prevents any current flowing through the bottom coils between the contacts A, B, but all the current passes through the top coils; (2) there is a short

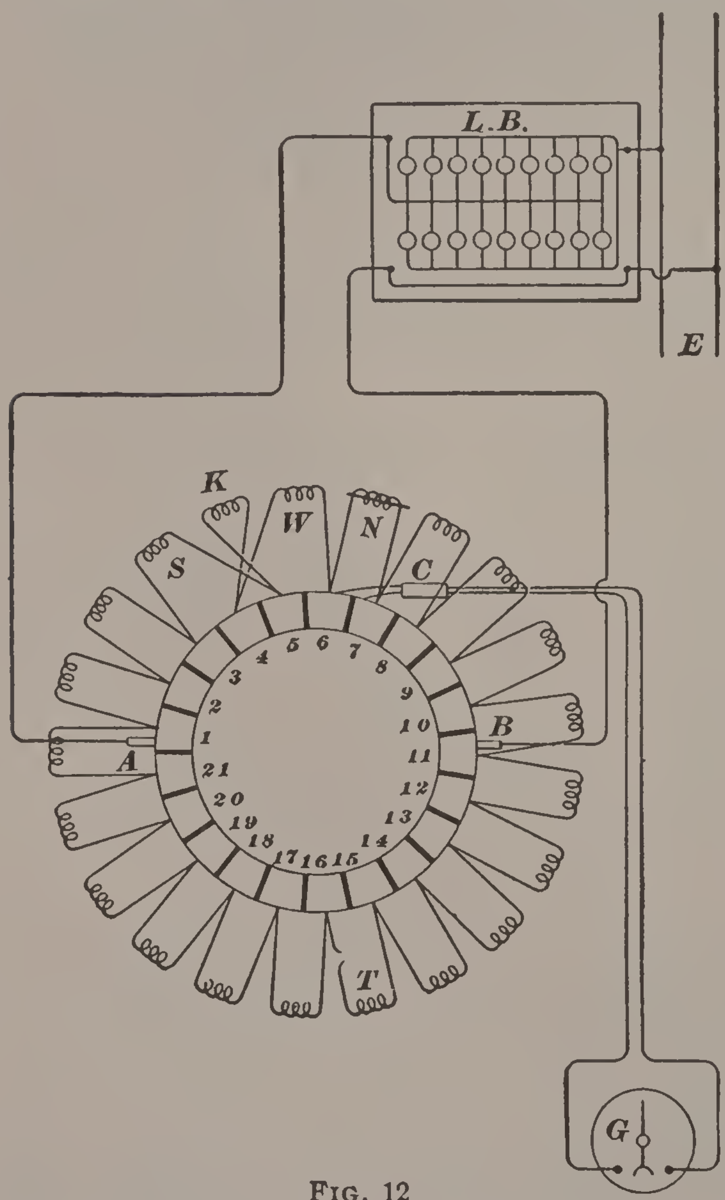


FIG. 12

circuit in coil *N*; (3) the commutator leads of coils *S*, *K*, *W* are mixed. All these defects are indicated in the figure.

58. The test is carried out as follows: Adjust the lamp bank until the voltmeter gives a good readable deflection when *C* is in contact with what are supposed to be good coils. The amount of current required in the main circuit will depend on the resistance of the armature under test. If the armature is of high resistance, a comparatively small current will give sufficient drop between the bars; if of low resistance, a large current will be necessary. With the contact maker *C*, the operator runs over several bars to obtain what is called the standard deflection with which to compare all the other deflections. The damaged part will often show a wide difference in deflection from the good coils. The deflection of the voltmeter will depend on the difference of potential between the bars. If everything is all right, the difference of potential between each pair of consecutive bars will be practically the same.

No deflection will be obtained on the lower side, except when bars *15* and *16* are bridged. There will then be a violent throw of the needle, because the voltmeter will be connected to *A* and *B* through the intervening coils. The break is thus located in coil *T*. As a temporary remedy for this, bars *15* and *16* may be connected by a jumper or piece of short wire. The defective coil *T* should, however, be repaired as soon as possible.

When the contact rests on bars *3*, *4*, a deflection about double the standard will be obtained, because two coils are connected between *3* and *4* in place of only one. When on *4* and *5*, the deflection will reverse, because the leads from *K*, *S* and *K*, *W* are crossed; but it will not be greater than the standard, because only one coil is connected between *4* and *5*. Between *5* and *6* a large deflection will be obtained as between *3* and *4* and for the same reason. Between *6* and *7* little or no deflection will be obtained, because coil *N* is short-circuited, and hence there will be in it little or no drop.

If a coil has poor or loose connections with the commutator

bars, the effect will be the same as if the coil had a higher resistance than it should, and hence the deflection will be above the normal. In practice, after one has become used to this test, faults may be located easily and rapidly. It is best to have two persons, one to move *C* and the other to watch the deflections of *G*.

59. Locating Short-Circuited Armature Coils. Where there are a large number of armatures to be tested, as, for example, in electric-railway repair shops, an arrangement similar to that shown in Fig. 13 is very convenient

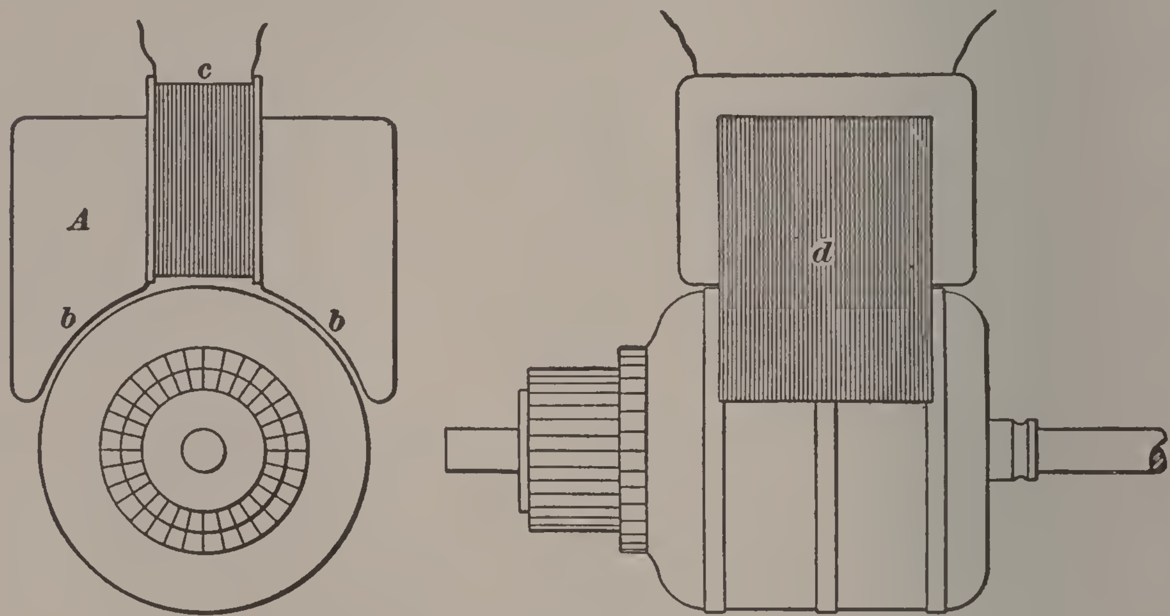


FIG. 13

for locating short-circuited coils. *A* is a laminated iron core with the polar faces *b*, *b* (in this case arranged for four-pole armatures). This core is rectangular and is wound with a coil *c* that is connected to a source of alternating current. The core is built up to a length *d*, about the same as the length of the armature core. When a test is to be made, the core *A* is lowered near the armature, and when an alternating current is sent through *c*, an alternating magnetization is set up through the armature coils. This induces an electromotive force in each coil; and if any short circuits exist, such heavy local currents are set up that the short-circuited coils soon become hot or burn out, thus indicating their location. If the armature is rotated slowly, it is possible to tell when a short-circuited coil comes under *b*, *b*

by the increased current taken by coil *c*. If an armature with a short-circuited coil is revolved in its own excited field, the faulty coil will promptly burn out, so that this constitutes another method of testing for such faults. To cut out a short-circuited coil, temporarily disconnect its ends from the commutator, bend the ends back out of the way, tape them so that they cannot touch each other, and connect the two bars from which the coil ends were disconnected by a short piece of wire, or jumper. It is always better, however, to replace the defective coil, because, if the turns are short-circuited on each other, the coil may persist in heating and thus damage other coils.

REPAIRS

60. Field Coils.—In case of accident to parts of the machinery, it is sometimes very convenient to make repairs on the spot, saving the time lost in sending the injured apparatus to the makers. There is usually no difficulty in rewinding field coils in a lathe. First weigh the old coil and, in removing the wire, note carefully the method of connecting, the size and insulation of the wire, and the insulation on the spool. Rewind the coil, using exactly duplicate features as nearly as possible, unless it is plainly evident that the conditions can be improved.

If necessary to make a joint in the wire, the ends of the wires should be rubbed bright with fine sandpaper, twisted firmly together, and soldered with a hot iron, using a non-acid flux. Only solder enough should be left on the joint to make the connection between the wires solid. Remove all projecting ends or bits of solder, leaving a perfectly smooth joint and one occupying as little space as possible. The joint should then be well insulated with silk, cotton, paper, or adhesive tape.

61. Armatures.—To rewind an armature, in whole or in part, is usually a much more difficult task, and if the job be of much importance, the advice or assistance of an

experienced man should be obtained. If such work be attempted, proceed slowly, carefully noting connections, insulations, etc. in removing the old portion, and duplicate all these features, as nearly as possible, in the new winding.

When complete, the binding wires should be replaced, and the winding tested for grounds, before connecting it to the commutator. It will be well, while replacing the winding, to make frequent tests for grounds or short circuits.

When being replaced, binding wires should be subjected to a considerable tension, so that when they expand as the armature heats up they will not become loose. They should be soldered together quickly with a very hot iron, using as before only a non-acid flux.

62. Balancing an Armature.—Many makers balance armatures by means of small masses of solder secured to the binding wires. If these binding wires are replaced the armature must be re-balanced in order that it may run without excessive vibration. For this purpose two iron or steel straight-edges or ways, as shown in Fig. 14, should be provided.

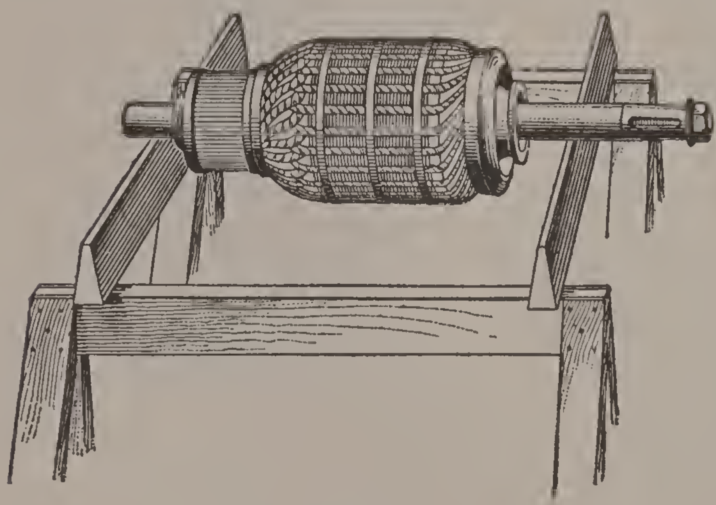


Fig. 14

These should be from $\frac{1}{8}$ to $\frac{3}{8}$ inch wide on the upper edge and from 12 to 18 inches long, depending on the weight and size of the armature to be balanced. They should be set level and parallel, and at such a distance apart that the journals of the armature shaft will rest on them.

To balance the armature, it is placed on the ways, when it will turn over until the heavy side is beneath. A small weight, as a piece of solder, is then temporarily fixed to the upper part of the armature, which is then given a slight motion by the hand. It will settle in a new position, when another weight may be temporarily affixed to the armature, or a little of the

other weight removed, according to the judgment of the workman. This operation should be continued until the armature shows no decided tendency to remain in any one position; the weights may then be permanently fastened in place.

The method of repairing broken leads, connections, and the like may be readily seen from the nature of the fault. In any kind of repair, the object in view should be to replace the defective part so that it will be exactly as it was before being damaged, unless, as before stated, the conditions can be improved.

OPERATION OF DIRECT-CURRENT MOTORS

STARTING AND REGULATING DEVICES AND MOTOR CONNECTIONS

63. The preceding discussion regarding the selection, installation, and care of electrical machinery applies with equal force to both generators and motors. Each may develop faults in insulation, open circuits, short circuits, etc. and each may cause trouble by sparking. The tests and the remedies in each case are practically the same. In the operation of motors, however, there are some features requiring special mention. Auxiliary apparatus is usually necessary with motors and a brief description of some of the most commonly used *starting rheostats* and *speed controllers* will be given.

64. When motors are operated on constant-potential circuits, it is necessary to insert a resistance in series with the armature when starting the motor. In the case of a series motor, this starting resistance is also in series with the field. The resistance of a motor armature is very small, and that of a series-field is also small, so that if the machine were connected directly across the circuit while standing still, there would be an enormous rush of current, because the motor would be generating no counter electromotive force.

For example, if a shunt motor of which the armature resistance is .1 ohm, were connected across a 110-volt circuit while the motor was at a standstill, the current that would flow momentarily would be $110 \div .1 = 1{,}100$ amperes, the amount being limited only by the resistance and inductance of the armature. The rush of current through a series motor would not be quite so bad, as the field winding, owing both to its resistance and its inductance, would help to choke back the current. *Inductance* is the property of an electric current of producing a magnetic field around its conductor. This magnetic field, which moves during any variation in the current strength, has the ability of inducing an electromotive force in the electric conductor itself as well as in any adjoining conductor. The effect of this induced electromotive force is to retard an increase or a decrease in the existing current strength. Hence, in a long conductor, such as a coil, a certain period of time is required for a current to reach its full strength, and when once reached, any variation is resisted by the inductance.

65. The **starting rheostat,** or **starting box,** is a resistance divided into a number of sections and connected to a switch by means of which these sections can be cut out as the motor comes up to speed. When the motor is running at full speed, this resistance is completely cut out, so that no energy is lost in it. Starting rheostats are made in a great variety of forms and sizes, but the object is the same in all of them, that is, to provide a resistance that may be inserted when the motor is at rest and gradually cut out as the motor comes up to speed.

SHUNT-MOTOR CONNECTIONS

66. One method of connecting a shunt motor to constant-potential mains is shown in Fig. 15. The lines leading to the motor are connected to the mains through a fuse block *D*, from which they are led to a double-pole knife switch *B*. One end of the shunt field *F* and one brush are connected to terminal *1* of the motor; the other field terminal is connected to terminal *2*, and the other brush to terminal *3*, which is connected to one rheostat terminal. One side of the main

switch connects to terminal *1*; the other side connects to terminal *2* and also through the starting rheostat *C*, to terminal *3*. As soon as the main switch is closed, current will flow through the field *F*. When the rheostat arm is moved over, current will flow through the armature *A* and the motor will start; as the handle is moved over slowly to the last point the motor gradually attains its full speed.

67. Fig. 15 shows connections for a motor having a three-point terminal block, one point for each line wire and a point for one field terminal, the other field terminal being brought directly to a brush. Modern motors are usually provided with a separate terminal point for each field and armature lead; that is, a four-point block for a shunt motor. With such a block, the direction of current through either the field or armature can be reversed independently of the other, making it easy to reverse the direction of rotation of the armature. Usually such reversals are provided for in a controller so that a movement of the controller handle will reverse the direction of rotation.

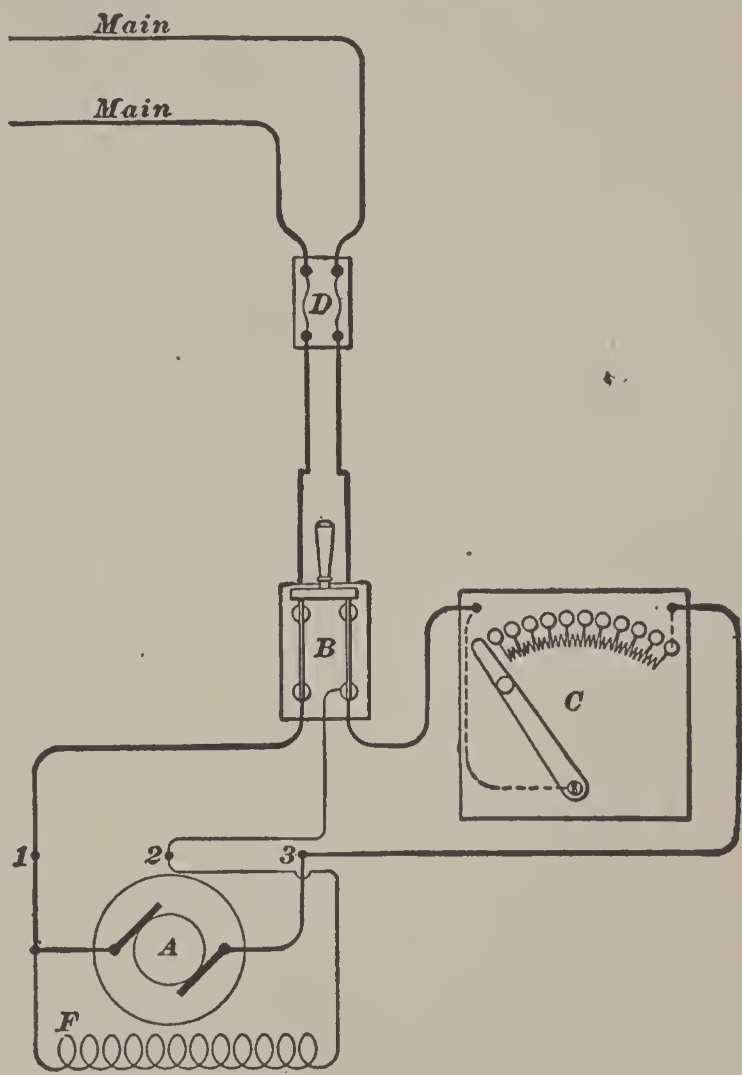


FIG. 15

68. Methods of Connecting.—Fig. 16 shows three methods of connecting a shunt motor. The switches are shown as single pole for sake of clearness of diagram. In Fig. 16 (*a*), the shunt field is excited as soon as the switches

are thrown; this is the method used in Figs. 15 and 18. In Fig. 16 (*b*), the shunt field is not excited until the rheostat lever is thrown on to the first button, and when the lever is moved over to its full-on position the field current must flow back through the armature resistance; this is objectionable though as the resistance is usually low and the field current

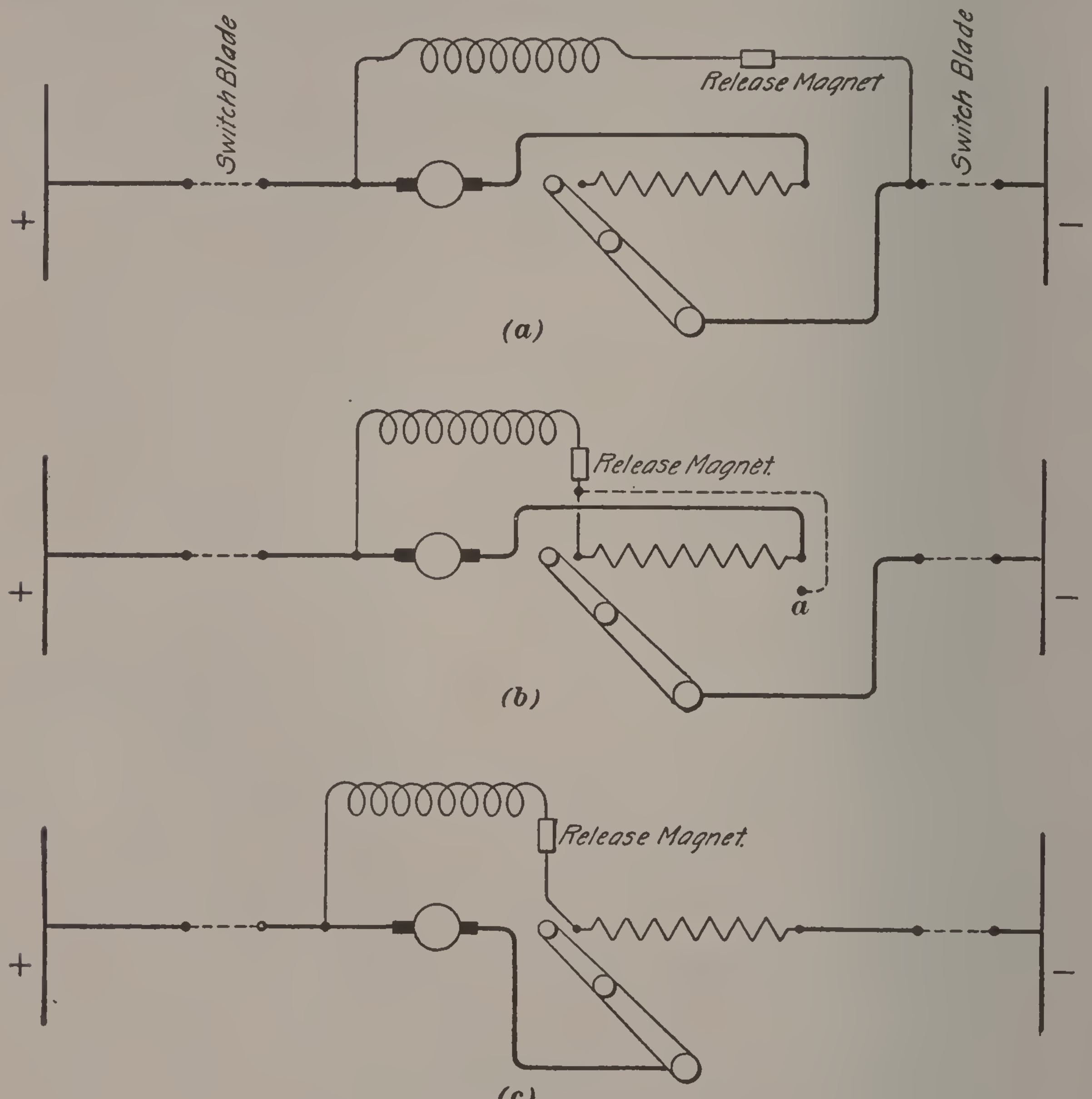


Fig. 16

small, little harm results. On some rheostats, an auxiliary contact and path is made, as shown by *a* and the dotted line, to lead the field current around the armature resistance when the lever is in the full-on position. A wrong connection frequently made is shown in Fig. 16 (*c*). The shunt field, instead of being connected across the line, is connected directly across the armature terminals when the lever is on

any of the contacts and hence receives only the voltage applied to the armature.

69. Automatic, No-Voltage-Release, Starting Rheostat.—In Fig. 15, the simplest type of rheostat was shown in order to make the connections as clear as possible; but such rheostats are now used but little, because they afford no automatic protection. Suppose that the attendant shuts down a motor by opening the main switch, but forgets to move the rheostat arm back to the off-position. When the switch is again closed, the armature, not being protected by the rheostat resistance, may be injured by the rush of current. Again, if the power should momentarily go off the line, something that may frequently happen, the motor will slow down and possibly stop. When the power is thrown on again, the motor armature receives full voltage unless the rheostat lever has, in the meantime, been moved to the full-off position. For these reasons, it is customary to arrange on almost every starting rheostat what is called an **automatic, no-voltage-release mechanism,** so that the rheostat handle will fly back to the off-position whenever the power is cut off from the motor. Fig. 17 shows a simple form of automatic rheostat made by the General Electric Company. The automatic feature consists of an electromagnet A in series with the motor field. The lever C is moved over against the action of a coiled spring, and is held at the full-on position by the attraction of magnet A for the armature B. Fig. 18 shows the rheostat connected to a motor. If the current supply be interrupted, the current in coil A will gradually decrease as the motor slows up and the counter electromotive force falls. The pull of the

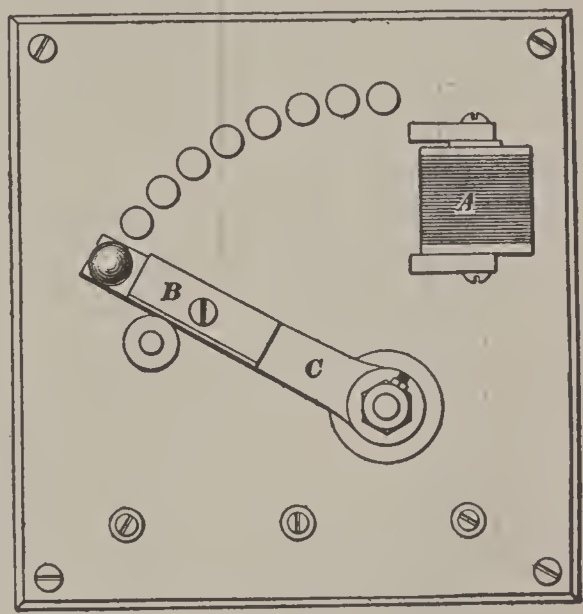


Fig. 17

magnet becomes weaker, until finally the armature B is released, and the arm flies back to the off-position. With such a rheostat the proper way to stop the motor is to open the main switch and let the rheostat take care of itself.

The automatic release magnet, instead of being connected in series with the shunt-field circuit, is sometimes connected, with or without a resistance in series, directly across the main circuit, so that the release coil is excited independently of the

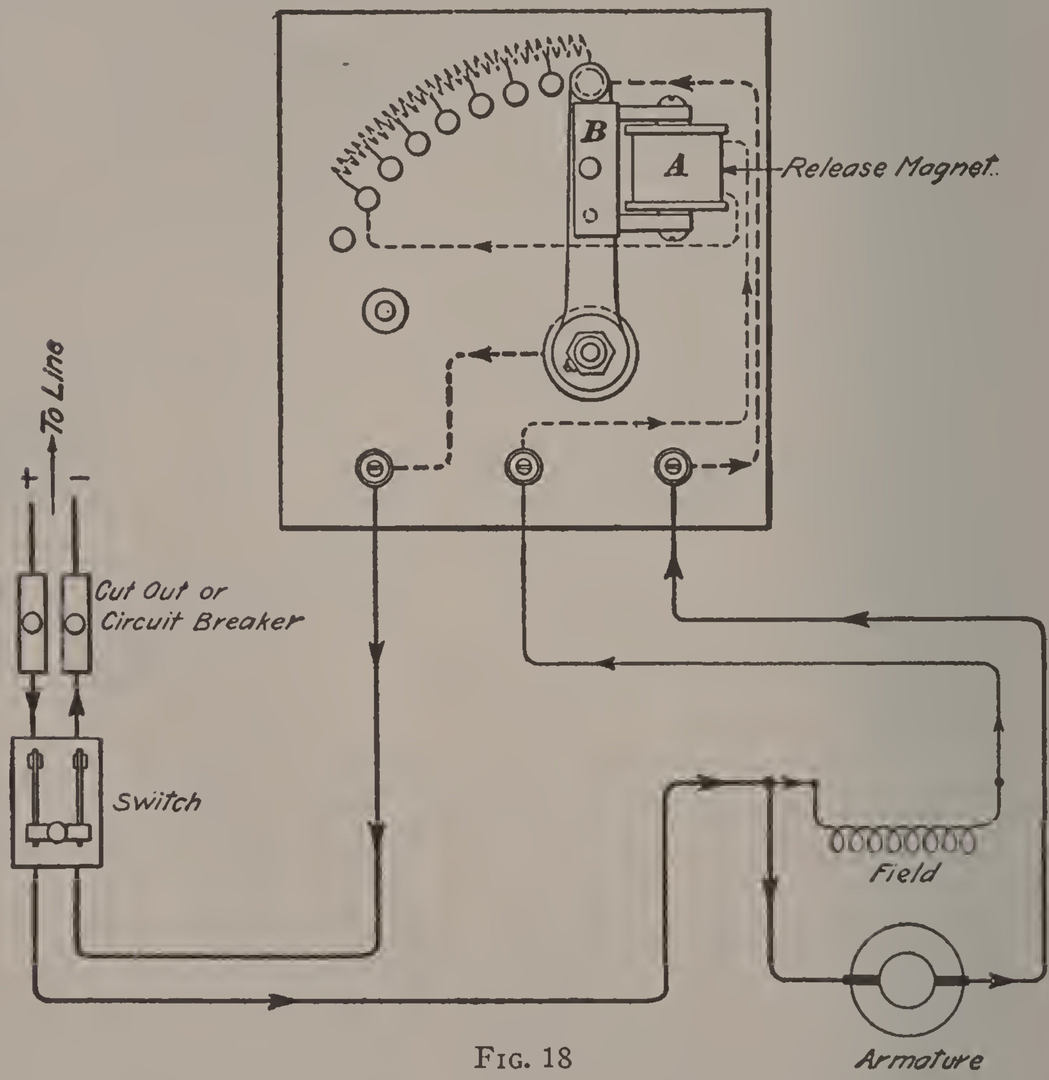


FIG. 18

shunt-field current. This is nearly always the case with rheostats for series-wound motors and some manufacturers adopt this plan for all their no-voltage magnets.

70. Overload protection is also incorporated with starting devices by arranging a magnetic latch to release the switching device if the current in the armature becomes too great for safety. A release of this sort that operates by demagnetizing the low-voltage release magnet is not effective against

overloads while starting a motor, since it affords protection only when the switching device is in the running position. The starter shown in Fig. 19 has an overload release that is effective whenever the starting lever *b* is over any of the resistance contacts.

The connections are shown in Fig. 20, in which similar letters indicate similar parts. These connections are the same in principle as those shown in Fig. 16 (*b*). The wrong connections shown in Fig. 16 (*c*) are made by interchanging the wires coming to the two binding posts on the rheostat; that is, the one marked *Arm*, Fig. 20, and that to the left of it. The low-voltage release coil *a* is energized when the starting lever *b* rests over any of the contacts *1*, *2*, *3*, etc., provided the overload release lever *c* remains in the position shown in both illustrations. The overload coil *d* is connected in series with one of the line conductors, so that all current to the motor must flow through this coil, the release lever *c*, starting lever *b*, starting resistance, to the armature as well as to the no-voltage release *a*, and the shunt field.

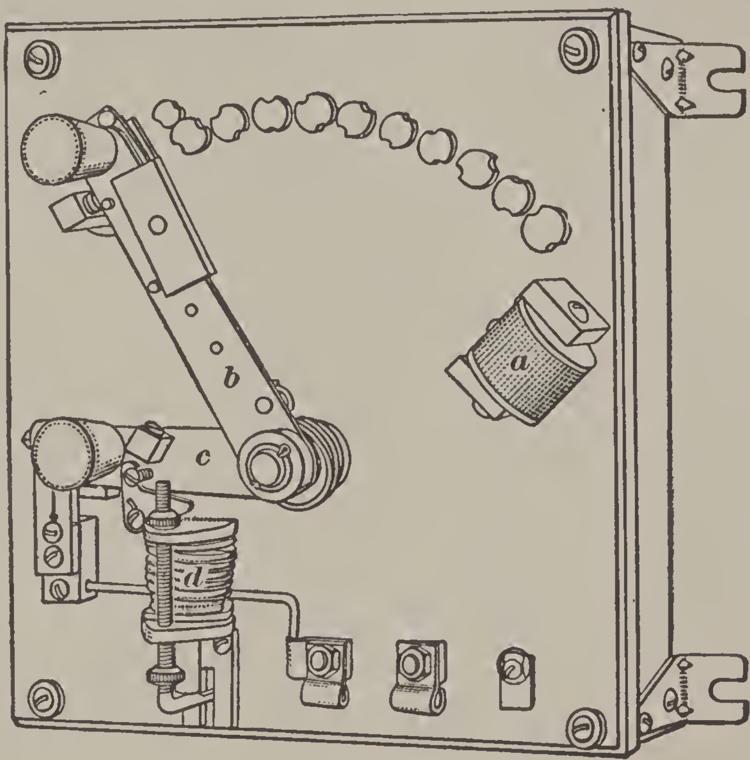


Fig. 19

If the motor is so overloaded that the current required exceeds a predetermined amount, the core of the electromagnet *d* is pulled upwards and swings the small catch to the left, thus releasing a pin held by it and allowing the lever *c* to be pulled up by a spring and open the circuit. The magnet *a* is then demagnetized and releases the lever *b*, which returns to the off-position. The arrangement on this rheostat is such that the arm *c* cannot be closed unless the lever *b* is in the off-position. The field connections shown by the full lines are those of a

shunt motor; the series field of a compound-wound motor is connected as shown by the broken lines, the direct connection, indicated by the full line between the points *e* and *f*, in that case being omitted.

71. Starting and Stopping a Motor.—Starting a motor with a starter similar to that shown in Figs. 18 and 19 is accomplished by first closing the line switch and then moving the starting lever over the row of resistance contacts, frequently called *steps* or *points*. The movement should be slow enough to allow the motor speed to accelerate smoothly. On the point at the extreme right, the lever is held by the low-voltage retaining magnet; this is the point on which the lever remains while the motor is running and is therefore called the *running point*. The lever will not remain at rest on any intermediate point and must not be held there longer than necessary for the speed to pick up.

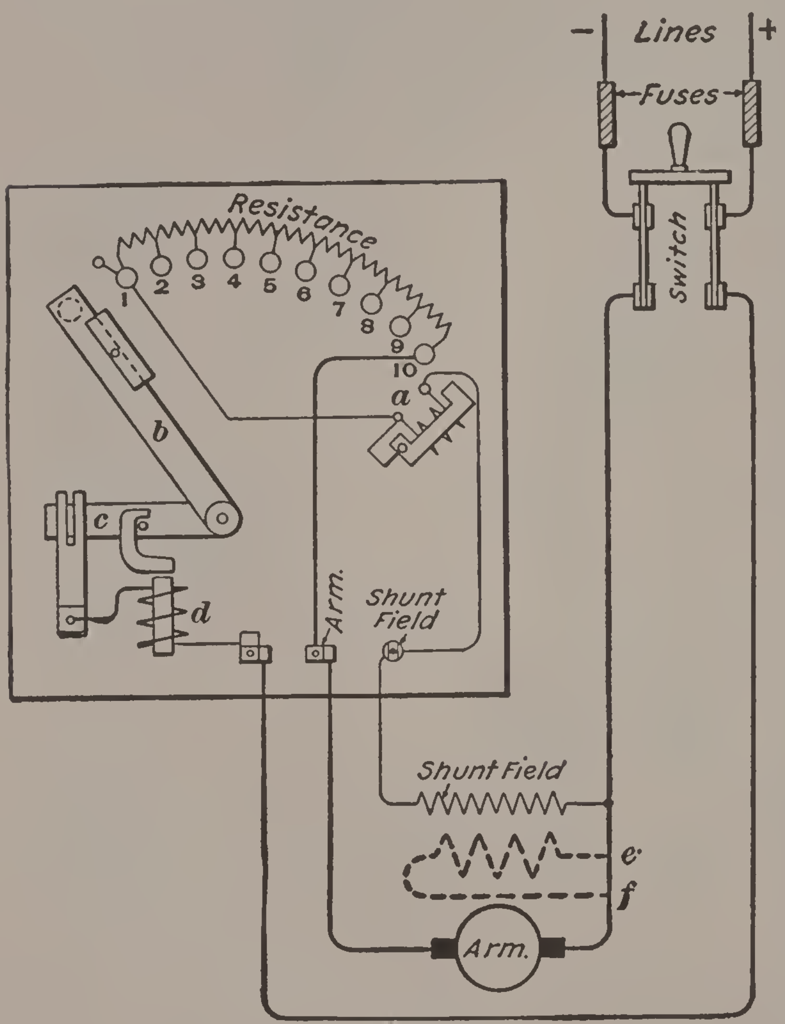


FIG. 20

Stopping a motor with any of the starters illustrated is generally best accomplished by opening the line switch or circuit-breaker. Such a circuit-opening device should be a part of every motor installation, as indicated in Fig. 20. On opening this switch the motor speed will decrease until the magnets release the switching devices, which will automatically return to position for the succeeding start.

72. Automatic Starting Switches.—The automatic starter consists of a combination of switch units which close automatically, each successively cutting out a section of resistance when the motor has accelerated to the proper point. One of these *switch units*, or *contactors*, is shown in Fig. 21. These contactors are made especially for starters and are variously called *series switches*, *series contactors*, and *magnetic lock-out switches*, the last name referring to the method by which their operation is delayed.

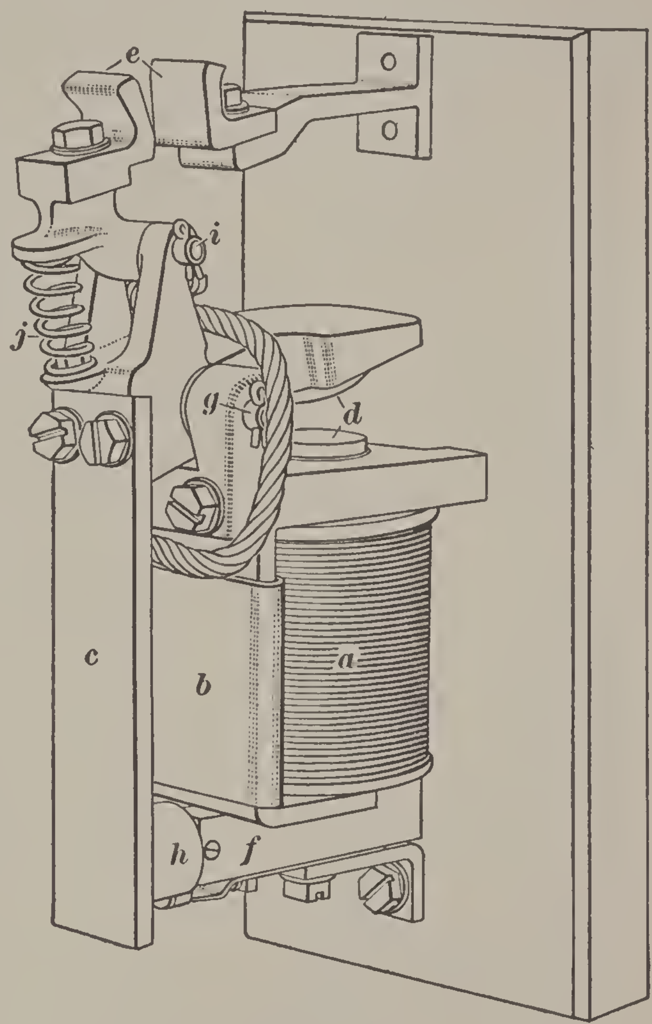


Fig. 21

The magnet coil *a* is series-wound, that is, it carries the armature current, and the switch is so made that it cannot close while the current through this coil exceeds the predetermined value for which the adjustments are made.

Two return paths are provided for the magnetic flux outside the magnet core, one through a *magnetic shunt b* and the other through a vertical iron strip *c* attached to the moving element. The magnetic pull across the air gap *d* tends to close the contacts *e*, while the magnetic pull between the lower end of the iron strip *c* and the pole *f* tends to hold the contacts open. A copper band around the magnetic shunt *b* prevents sudden changes of flux, and the cross-section of this shunt is so small that it becomes highly saturated when the magnetizing force is high. When the current in the coil exceeds the adjustment, enough flux passes through the iron strip *c* to hold its lower end against the pole *f*. But when the current decreases, the flux through the strip *c* becomes less until the pull across the gap *d* becomes superior,

and the moving element turns on its pivot *g*, closing the contacts *e* and causing the lower end of the strip *c* to swing outwards.

73. A self-locking nurled nut *h*, Fig. 21, serves to adjust the length of the gap *d* and thus adjusts the current at which the switch closes. The contacts *e*, in closing, touch first near the tips and then rock back toward the heels by turning the arm to which the moving contact is attached around the pivot *i*. In thus turning, the spring *j* is compressed so that when the contacts open, the rocking motion is reversed and the circuit is opened at the tips of the contacts. To prevent the formation of destructive arcs on opening, **arc shields,** made of refractory material, are employed.

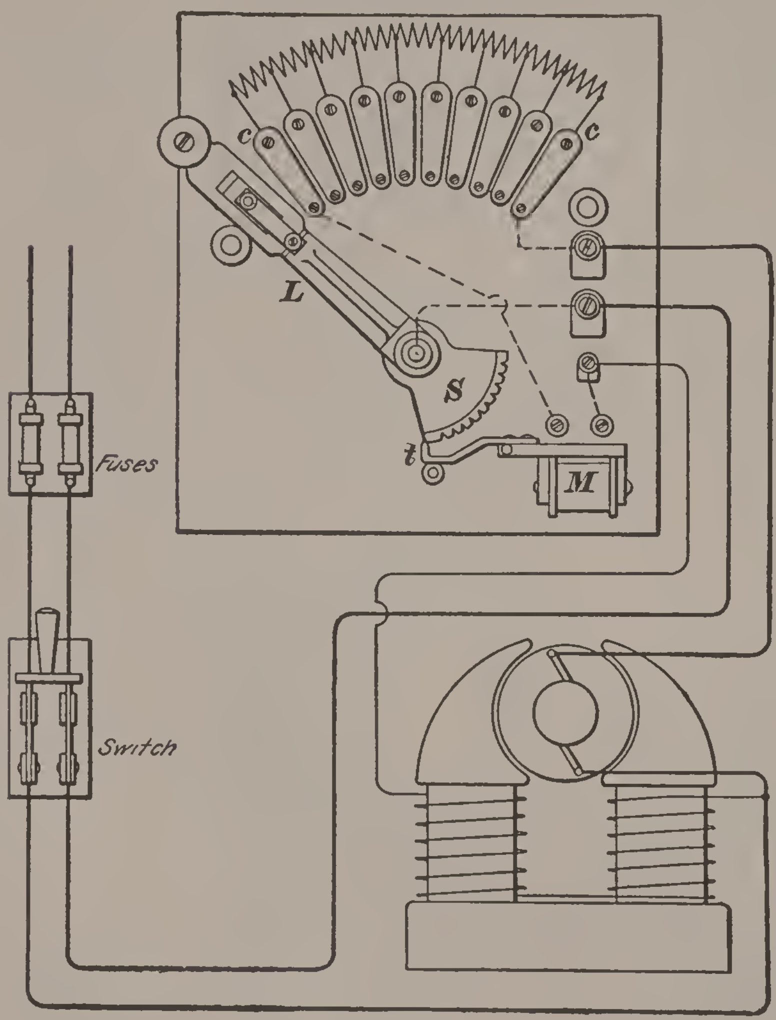


FIG. 22

When several of these contactors are properly grouped in a starter and adjusted, they will close automatically, as soon as the line switch is closed, in the sequence of time necessary to bring the motor up to speed. In this case, the delay in operation of each switch depends entirely on the current in the circuit.

74. Speed-Regulating Rheostats.—Speed-regulating rheostats, often called **speed regulators,** are very similar in construction, in appearance, and in connections to starting rheostats except that regulators, owing to their greatly increased carrying capacity, are much the larger. The chief difference, however, between the two is that while a starting rheostat has

resistance so proportioned as to carry the starting current required by the motor armature for only a few seconds, usually not over 15, a speed regulator has resistance designed to carry the armature current continuously. The starting rheostat lever should, therefore, never be held longer than 2 or 3 seconds on any step except the last, on which the resistance is all cut out. The speed-regulator lever is usually arranged to be held automatically on any desired step. Fig. 22 shows the connections of an automatic speed regulator for a shunt motor. The segment S, which turns with the lever L, is fixed in any required position by a pawl or catch t engaging one of the notches in S by the action of the magnet M. The notches are so distributed that each corresponds to the position of the lever squarely over one of the contact segments c, c. If the voltage of the circuit fails or if the switch is opened, the magnet M releases the pawl t and the lever flies back to its initial position. In this type of regulator, the contact segments c, c are renewable and may be easily replaced if they become worn or burned.

SERIES- AND COMPOUND-MOTOR CONNECTIONS

75. Connections for shunt motors have been discussed first because they are the most complicated and the most

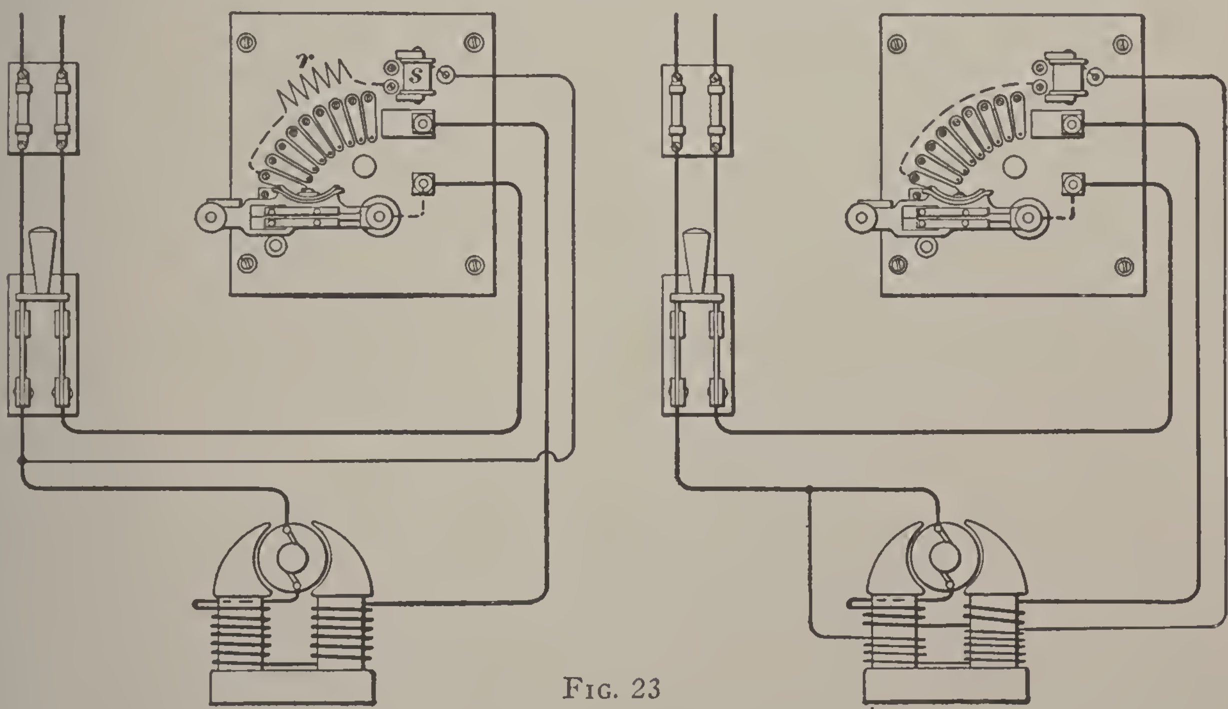


FIG. 23

common. If these are fully understood, the methods of connecting the other field windings will then be easily derived.

Fig. 23 shows simple diagrams of connections for series- and compound-wound motor starters with automatic underload release. The release spool *s* of a series-motor starter is usually connected directly across the circuit with a resistance *r* in series unless the voltage of the circuit is very low, in which case the resistance is omitted.

Since its field helps to choke back the starting current, a series motor does not require so large a starting resistance as a shunt motor.

REVERSING THE DIRECTION OF ROTATION

76. If the current in either the field or the armature of a motor is reversed, the direction of rotation will be reversed; but if the current in both the field and armature be reversed, the direction of motion will remain unchanged. A series motor will, therefore, run in the same direction, whatever the direction of the current through the machine. Reversing the line connections to terminals *a*, *b*, Fig. 24, simply reverses the current through both armature and field and does not change the direction of rotation. In order to reverse the motor, either the armature terminals *c*, *d* must be interchanged, so as to reverse the current through the armature, or the terminals *d*, *b* must be interchanged, so as to reverse the current through the field. In mine locomotives and other electric-railway work, the motors are usually reversed by reversing the direction of the current through the armature, that of the current through the field remaining unaltered.

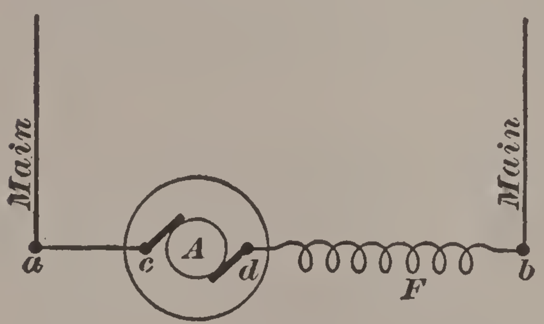


FIG. 24

To reverse a motor while it is running, it is necessary to insert a resistance in the armature circuit so as to reduce the speed or even bring the motor to rest before reversing the current through the armature. The counter electromotive force that the motor was generating just before reversal becomes an active electromotive force and helps to make the current flow through the armature as soon as the direction of the

flow is reversed. This causes a very large current to pass until the motor starts to turn in the opposite direction and builds up a reversed counter electromotive force; hence, the necessity of reducing speed or even stopping the motor before reversing it.

77. Reversing Switches.—In order to reverse the current in a motor armature so as to reverse its rotation, a **reversing switch** is placed in the armature circuit. Fig. 25 shows three common types of switch. That shown at (*a*) consists of two metal blades *a*, *b* hinged at *c* and *d* and connected together by an insulating cross-piece *e*. The blades can be swung from the position shown in the figure to that indicated by the dotted lines, by the rod *f*. The points *g* and *k* are connected by a wire conductor as indicated by the dotted line. In the first position, *c* and *d* are connected to *g* and *h*, while in the second position they are connected to *h* and *k*, which reverses the current in the armature. Fig. 25 (*b*) shows an ordinary double-pole, double-throw, knife switch used as a reversing switch. The middle clips are connected to the armature, while the top and bottom clips are

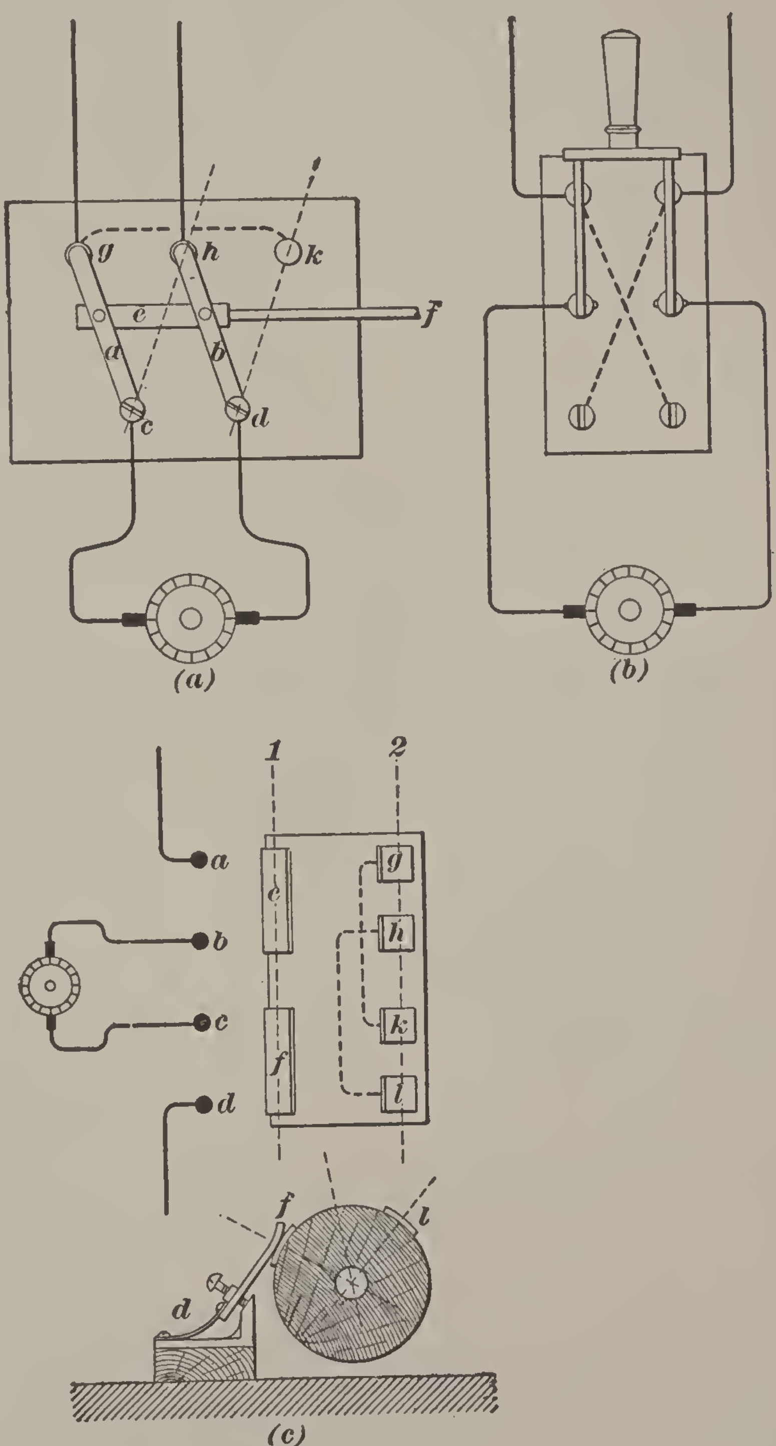


FIG. 25

cross-connected, so that when the switch is thrown up, the current in the armature is in one direction, and when it is thrown down, this current is reversed. The reversing switch shown in Fig. 25 (*c*) is of the cylinder type, and is used very largely for railway and hoisting motor controllers.

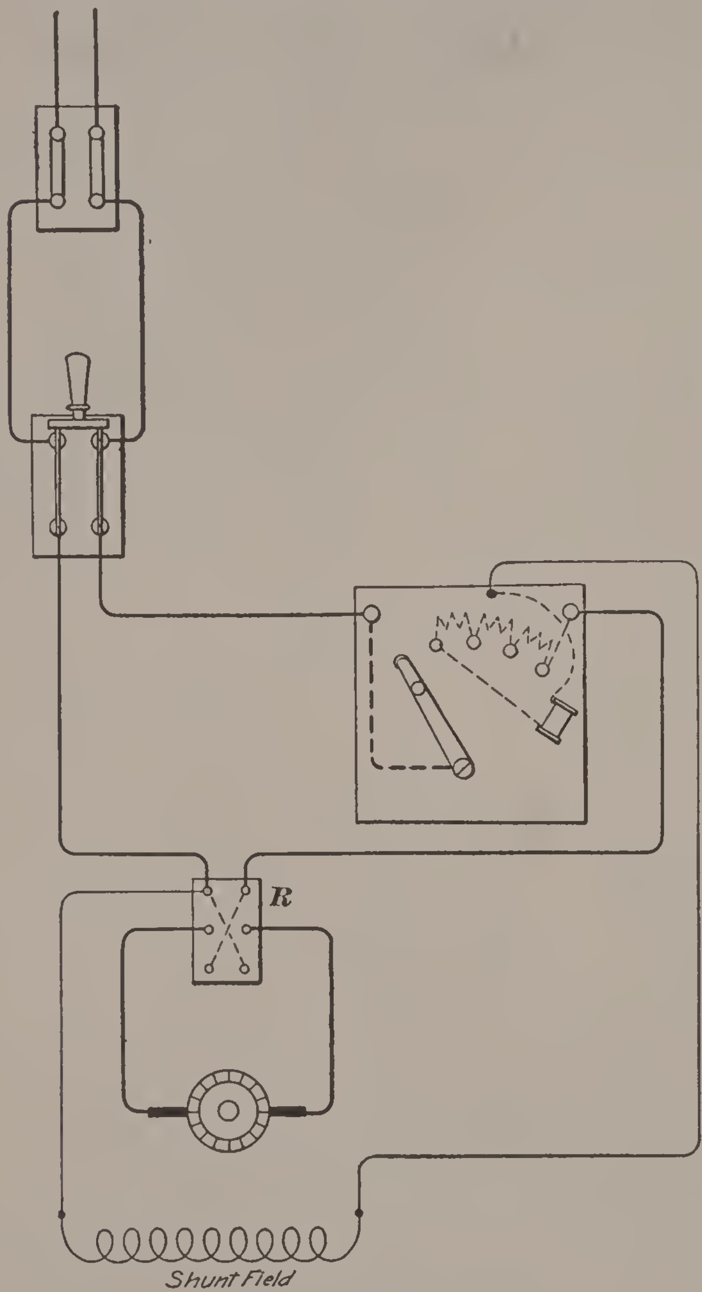


FIG. 26

The upper portion of this figure is a plan view of the cylinder showing the contact pieces *e*, *f*, *g*, *h*, *k*, *l*. The cylinder is usually made of wood or else pieces are insulated from it and they serve only to change the connections between contact fingers represented at *a*, *b*, *c*, *d*. The lower portion of the figure shows the end of the cylinder and the position of one finger *d* and contact pieces *f* and *l*, the other fingers and contact pieces being in direct line with those shown. When the cylinder is rotated so that the fingers rest on plates *e* and *f*, as indicated by the dotted line *1*, the current entering at *a* takes the path *a–e–b*, and, passing through the armature, traverses *c–f–d*. When the drum is turned so that the fingers rest on the contacts *g*, *h*, *k*, *l*, as indicated by the dotted line *2*, the path becomes *a–g–k–c* and passing through the armature in the reverse direction then traverses *b–h–l–d*.

78. Shunt Motor With Reversing Switch.—Fig. 26 shows connections for a shunt motor with reversing switch *R*.

The field is excited from the mains as soon as the rheostat arm is placed on the first point, and remains excited in the same direction regardless of the position of the reversing switch.

CONTROLLERS

79. For motors that have to be stopped, started, and reversed frequently, special types of starting devices are used. These are generally called *controllers*. For electric-railway work, these controllers are sometimes quite complicated, being designed not only to cut resistance in or out, but also to make various combinations of the two or more motors used on a car. An explanation of railway controllers will be found in *Haulage*, Part 3, so they will not be considered here. Controllers somewhat similar to those used on electric cars and locomotives are also used for stationary work, but when so used they are generally required to control but one motor, and hence are designed to simply cut resistance in or out and not to make series and parallel combinations.

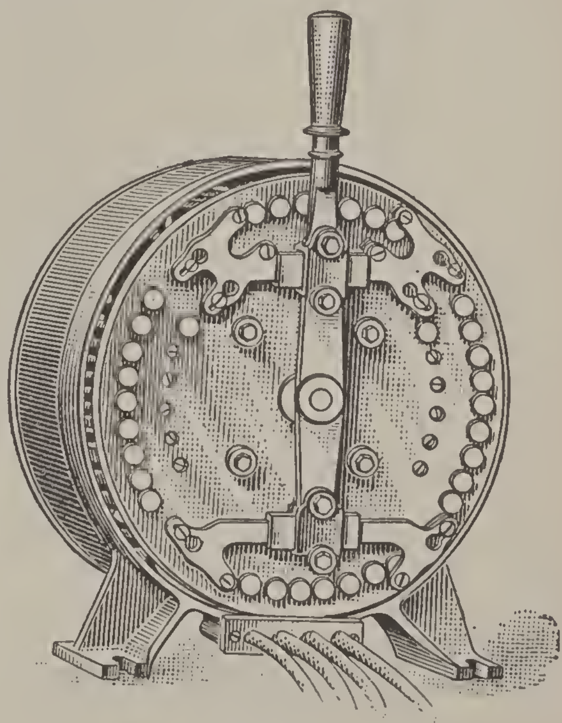


Fig. 27

The use of series motors in places calling for heavy service has resulted in the development of a large number of controlling devices especially adapted to work of this kind. For such service, the motor must be capable of being stopped, started, and reversed quickly, and the controller must be of simple and substantial construction.

Figs. 27 and 28 show typical crane controllers for motors of 5 and 30 horsepowers, respectively. All speed regulation is by armature control, and in each case the motor can be operated in either direction, depending on the way in which the handle is moved from the *off-position*, or the position in which the motor circuit is open. Both controllers are shown so arranged

that the operators must stand near them, but each can be arranged for operating from a distance by means of ropes or rods. Thus, the smaller controller can be operated by ropes from the floor underneath the crane, and the larger one can be mounted outside the crane cage and operated by means of a bell-crank and a connecting-rod.

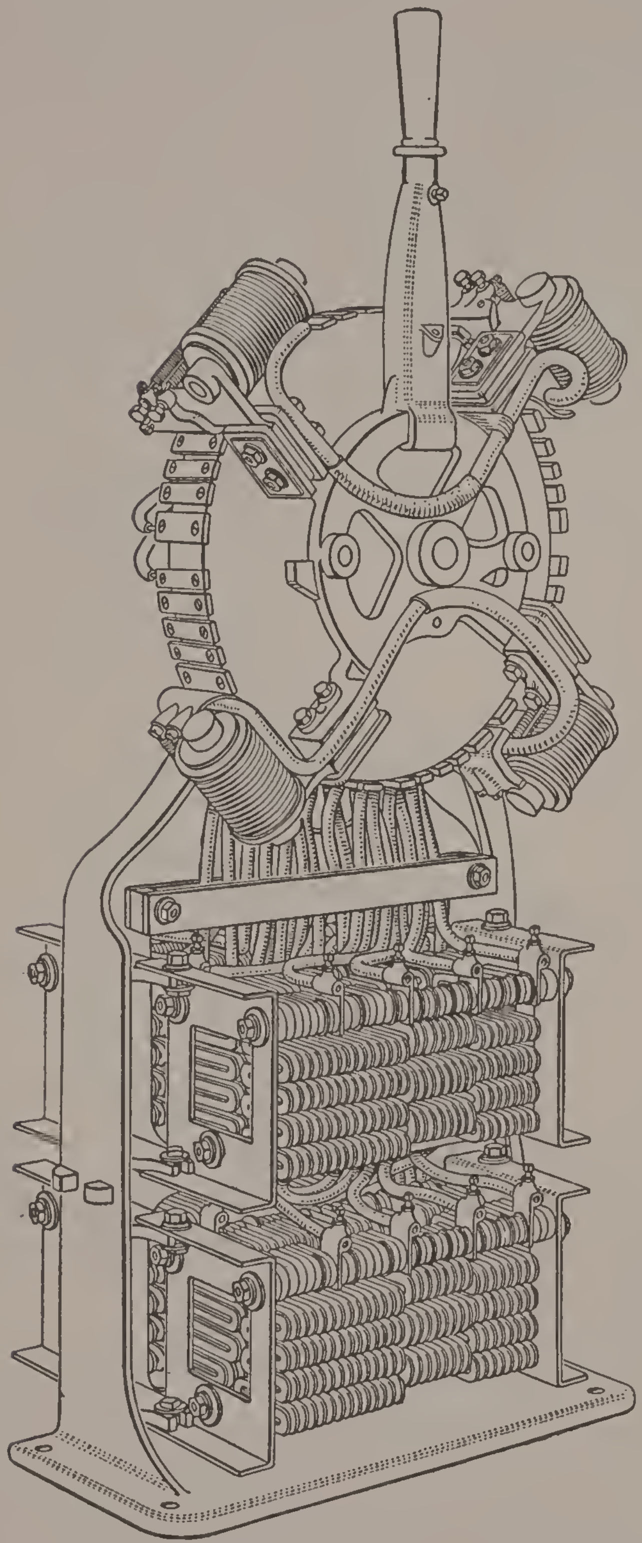


Fig. 28

80. The larger controller, Fig. 28, has two pairs of moving contacts, those of each being connected in parallel. A magnetic blow-out coil, Fig. 29, mounted near each contact and connected in series with it sets up a strong magnetic field between the poles *a* directly through the space where arcs form between the moving and the stationary contacts; the arcs are thereby promptly disrupted, thus minimizing injury to the contacts.

81. Drum Controllers. Drum controllers arranged for adjusting armature-control resistance only are much used in connection with heavy crane and hoist service, as well as for railway work. The upper portion of Fig. 30 shows external connections of such a controller, with motors having different types of field windings. The lower portion of the figure shows the internal connections. The stationary fingers in the controller are represented by the circles in the center;

fingers R_5, R_4, etc., are connected with resistor terminals similarly lettered and the other terminals with the armature and the line. The moving drum segments are represented by small rectangles, and the drum positions, or steps, are indicated by the vertical dotted lines *1, 2, 3, 4, 5* through these rectangles. Blow-out coils are provided where necessary to prevent destructive arcing.

82. Turning the drum either way from off-position moves segments under the fingers in a way to complete a circuit through the motor and to cut out the control resistance step by step until all is out on the fifth step. The direction of current in the motor armature and, consequently, the direction

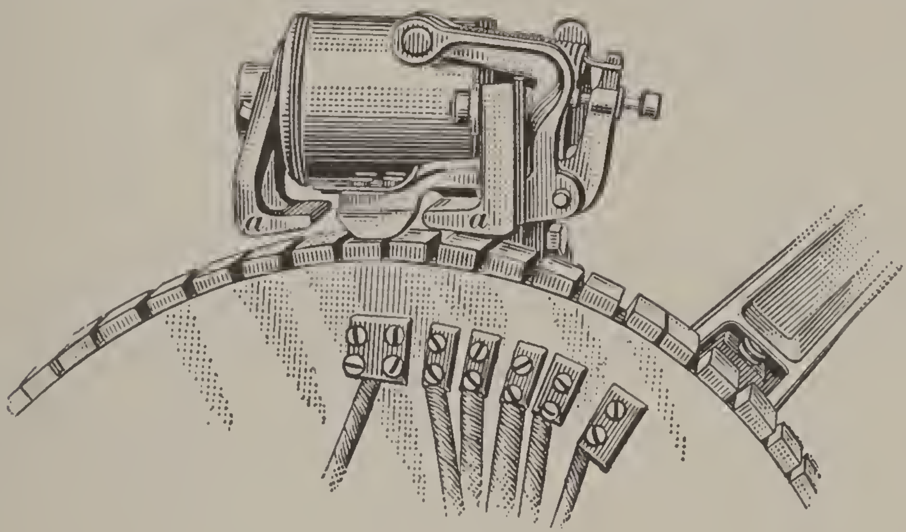


FIG. 29

of rotation of the motor depends on the direction in which the drum is turned.

83. Automatic Controllers.—Automatic controllers composed of magnetically operated switches, or contactors, are made for many kinds of industrial service. Shunt contactors are generally used for speed-control purposes, and the interlocking contacts are so interconnected that each switch controls the operation of the next switch in the series. By means of these switches and suitable safety devices, an operator with a simple master controller can exercise perfect control over large motors in difficult processes where starting, stopping, and reversing are frequently required. The *master controller* is a simple switching device to control the exciting current of the magnets on the contactors.

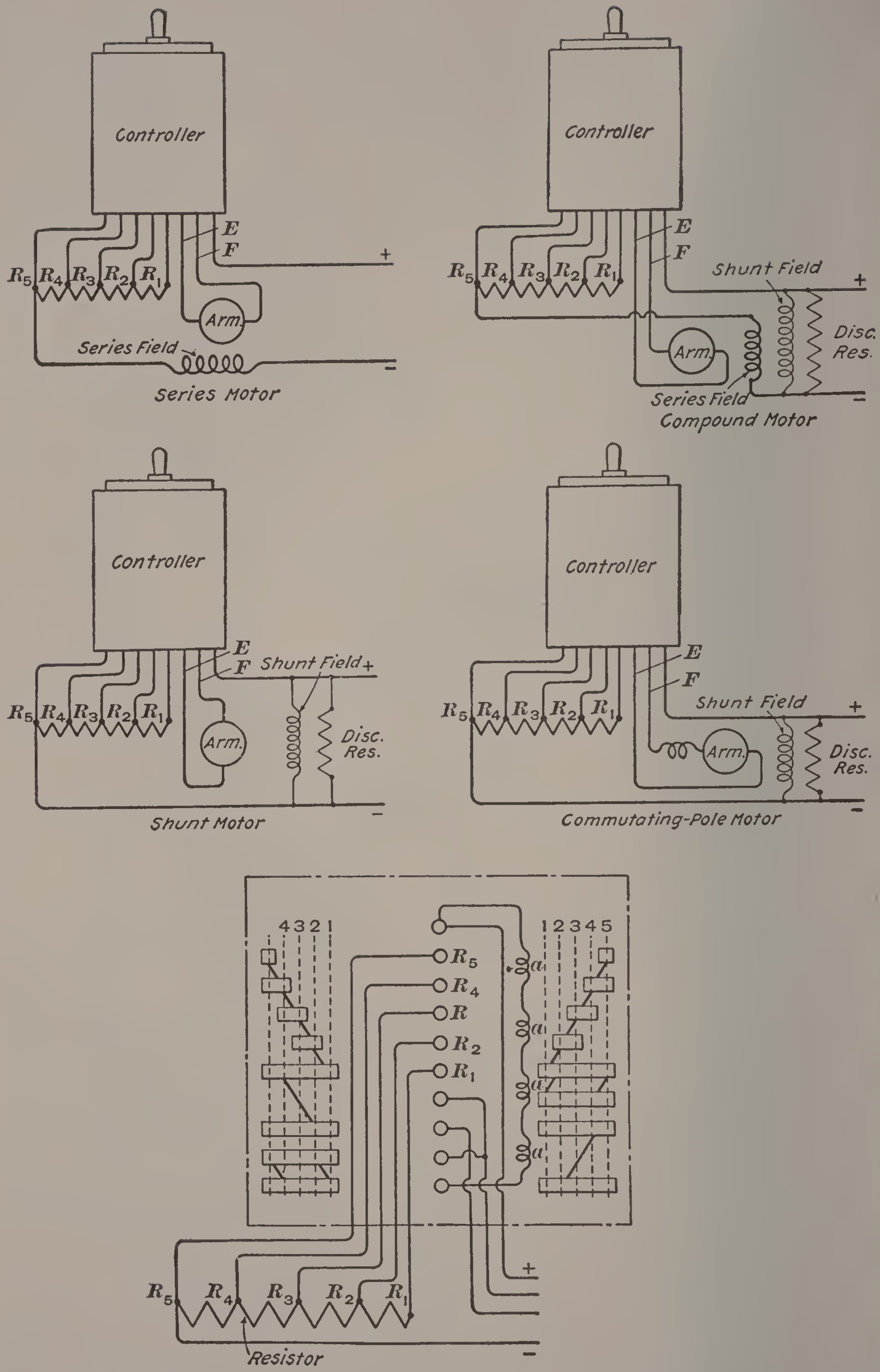

Controller
E
F
+
R_5 R_4 R_3 R_2 R_1
Arm.
Series Field
=
Series Motor
Controller
E
F
Shunt Field
+
R_5 R_4 R_3 R_2 R_1
Arm.
Disc. Res.
Series Field
=
Compound Motor
Controller
E
F
Shunt Field +
R_5 R_4 R_3 R_2 R_1
Arm.
Disc. Res.
−
Shunt Motor
Controller
E
F
Shunt Field
+
R_5 R_4 R_3 R_2 R_1
Arm.
Disc. Res.
−
Commutating-Pole Motor
4 3 2 1
1 2 3 4 5
R_5
R_4
R
R_2
R_1
a
a
a
a
+
R_5 R_4 R_3 R_2 R_1
Resistor
−

FIG. 30

SELF-STARTING RHEOSTATS

84. Sometimes is is necessary to have a starting rheostat arranged so that it can be controlled from a distant point, in which case the box has to cut out its starting resistance automatically. The most common method of accomplishing this is to provide the rheostat with a solenoid that, when energized, moves the contact arm and cuts out the resistance.

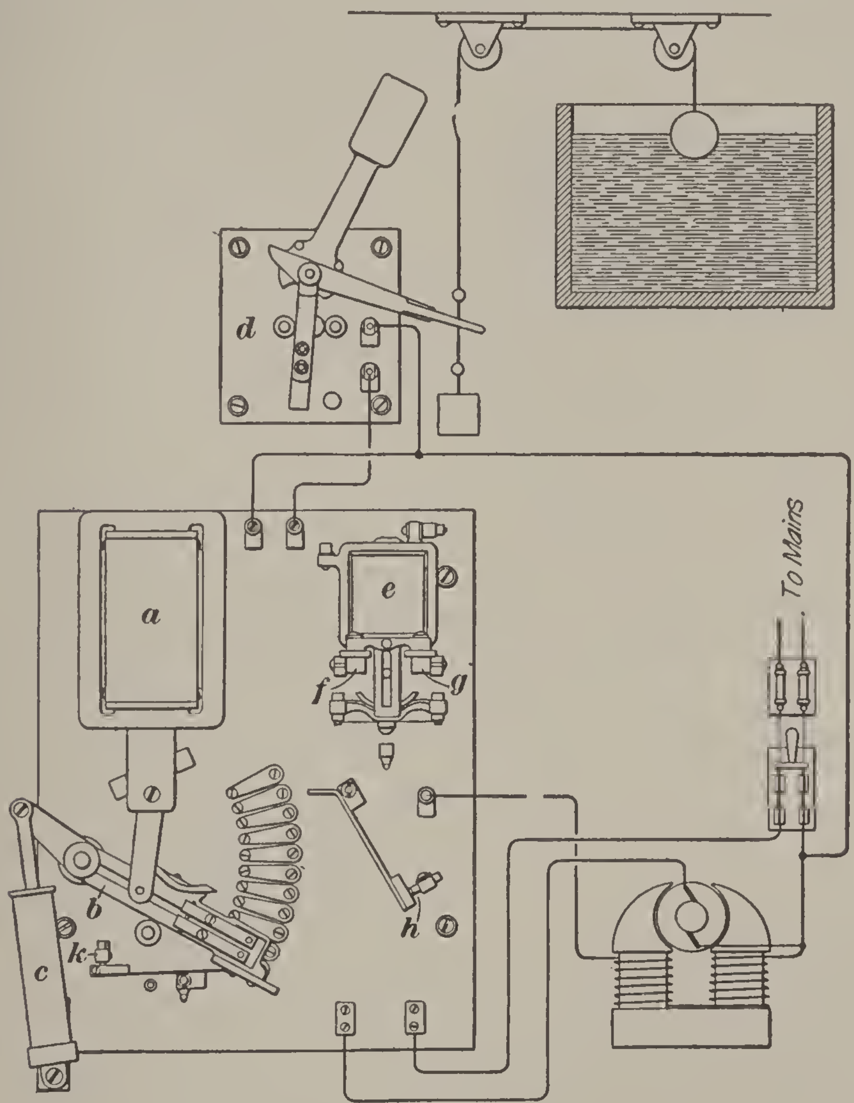


FIG. 31

85. Fig. 31 shows an example of an automatic starter as used to control a motor that operates a pump supplying water to a tank. The switch *d* controlling the motor is located at the tank, which may be some distance from the motor and its rheostat. The switch is opened and closed at high- and low-water marks by a float in the tank. The automatic closing of the switch *d* when the tank is empty operates the solenoid

switch *e* at the pump house, thereby raising its core and making contact between studs *f*, *g*. This closes the main circuit and energizes another solenoid *a*, which draws up its core, moving the arm *b* slowly over the contacts, its speed being controlled by the action of the oil dashpot *c*. By this means, the motor is started and brought gradually up to speed. The moment arm *b* leaves its lowest position, carbon points at *k* separate, throwing an incandescent lamp in series with coil *e*; and when the arm reaches its highest position, it causes the carbon points at *h* to separate, thus throwing another lamp in series with coil *a*. The lamps and their connections are not shown in the figure. When the magnet cores are in the lowest positions, a considerable current in each coil may be required to raise them; but when the cores have been drawn well into the coils, a small current in each is all that is necessary and connecting a lamp in series with each magnet not only prevents overheating the wire but also saves current.

STARTING A DIRECT-CURRENT MOTOR

86. When installing a motor in an isolated place where a voltmeter is not available, it is well to permanently connect an incandescent lamp across the circuit near the motor so as to supply a ready means of ascertaining whether power is on the line at any time. By using a key socket, or receptacle, the lamp may be switched off when not needed.

Before attempting to start the motor see that there is power on the line and then close the main switch. This may or may not allow a current to flow through the motor fields, according to the kind of winding and the method of connecting. Move the lever of the starting rheostat quickly and squarely to the first contact segment and let it stay there for 2 or 3 seconds. The motor should start at once and begin to increase in speed. Move the lever on from segment to segment, stopping on each but 2 or 3 seconds, until the full-on, or short-circuit, position is reached, where the lever should be firmly held by the retaining magnet. During this process, the motor speed should have gradually increased to full speed, the total time required to accelerate to

full speed being usually about 15 seconds. Do not hold the lever longer than indicated on any contact, unless the starting resistance be intended also for speed control. If the motor does not start when the lever is on the first contact, move quickly to the second. If still no start is made, move to the third and, if the machine fails to start, immediately open the main-line switch and look for the cause of the failure. The failure may result from any one or more of several causes, namely:

1. **Wrong connections,** of which the most commonly occurring example for shunt fields was indicated in Art. 68. Make sure that the shunt field obtains the full voltage when the lever is on the first step, and that the poles are magnetized.

2. An **overload** on the motor; when a motor is first installed, the current required to start its load as well as the running current after obtaining full speed should be ascertained. An ordinary motor intended for continuous service should not be expected to start a load requiring more than double its rating in amperes. This rating is usually stamped on the name plate. Motors intended for intermittent service, such as railway and hoisting work, are designed to start with almost any load up to what would actually stall the armature.

3. An **open circuit** due, possibly, to a defective switch, a broken wire or poor connection in the starting box, or the brush not making good contact with the commutator, or an open circuit within the motor itself.

4. A **short circuit,** which will nearly always make its presence and possibly its location known. Among the more common sources of short-circuiting are: short-circuited armature coils; short-circuited commutator; short-circuited field coils; brushes in the wrong position. If the armature coils or commutator are short-circuited, the machine may start and turn over part way and stop again. With a series field-coil short-circuited, the armature will start only under a heavy current, with accompanying sparking, and will acquire a high rate of speed. A wrong position of the brushes will usually be indicated by violent sparking. The correct position may be found by trial if not already marked on the frame.

OPERATION OF DYNAMO-ELECTRIC MACHINERY

Serial 839B (PART 2) Edition 2

DIRECT-CURRENT GENERATORS IN COMBINATIONS

GENERATORS IN SERIES

1. Generators are seldom run in series. As in the case of a series-connection of battery cells, a series-connection of generators adds their pressures but does not change the total current output. Occasionally in a long direct-current transmission line in the United States, usually a line carrying current for an electric railway, a series generator is connected in series with the main generators in the power house to raise, or *boost,* the voltage, such a generator being called a **booster.** The booster is driven at a constant speed and whenever no current is flowing out to the line, the booster, being series-wound, has no field strength, and hence generates no electromotive force; when a large current is flowing, the booster has a very strong field, and hence generates an electromotive force, which is added to that of the main generators. The amount of electromotive force generated by the booster depends on the amount of current flowing through its field and out to the line. In other countries, especially in some plants in Europe, a number of direct-current generators are connected in series to produce a pressure of several thousand volts for transmitting current over long distances.

Generally speaking, series-wound, shunt-wound, or compound-wound generators may be run in series with very little difficulty, the series field-winding, when there is one, always being connected in series with the line. But in most cases, the demand is for large current output rather than high voltage, and to increase the current requires parallel connection.

GENERATORS IN PARALLEL

2. Direct-current generators are frequently operated in parallel, the connections being as shown in Fig. 1, where, in order to make the connections as simple as possible, no field windings are shown. Each machine generates the same

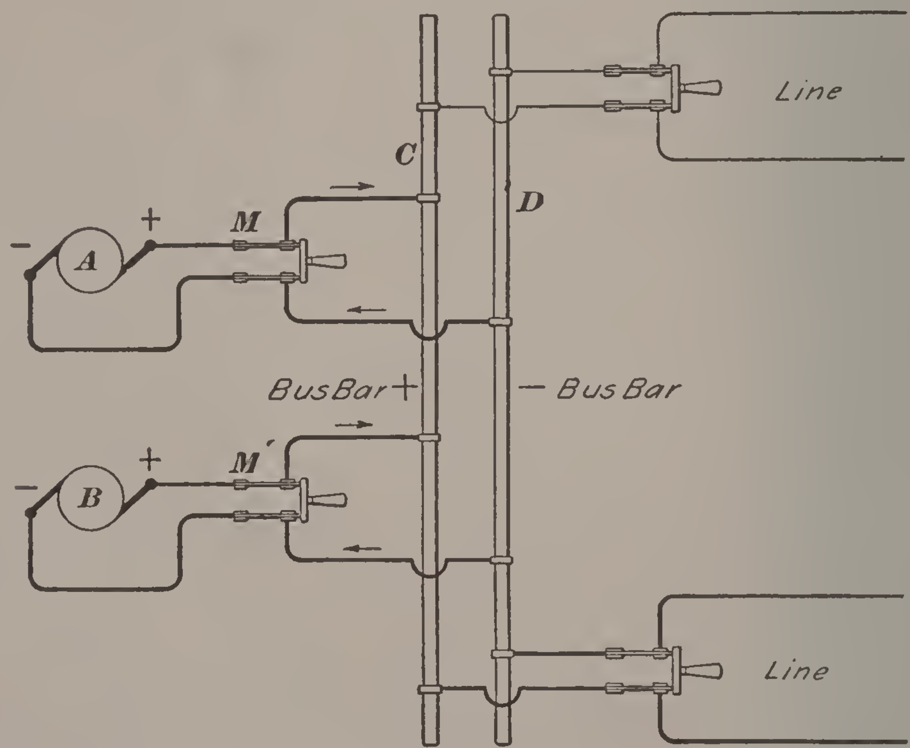


FIG. 1

voltage, and the pressure between the lines is the same as if a single machine were used; but the current delivered to the external circuits is the sum of the currents delivered by the several machines; hence, the outputs are combined by adding the currents from the several generators. Each machine delivers current through its main switch *M* or *M′* to the heavy conductors, or **bus-bars,** *C*, *D*, connected as shown. Like terminals of each machine must be connected to the same bus-bar.

It is not so easy a matter to operate machines in parallel as in series. It is evident that the voltage of each machine must be kept at the proper amount if the combination is to operate satisfactorily; for, suppose that the electromotive force of *B*, Fig. 1, should fall below that of *A*, then *A* will send current through *B* and run it as a motor, and *B* will thus be taking current from *A* instead of helping it feed into the line.

Series generators are seldom run in parallel; shunt generators are sometimes, but compound-wound generators are quite frequently so operated.

SERIES GENERATORS IN PARALLEL

3. Suppose two series generators to be connected as shown in Fig. 2 and assume that each machine is delivering one-

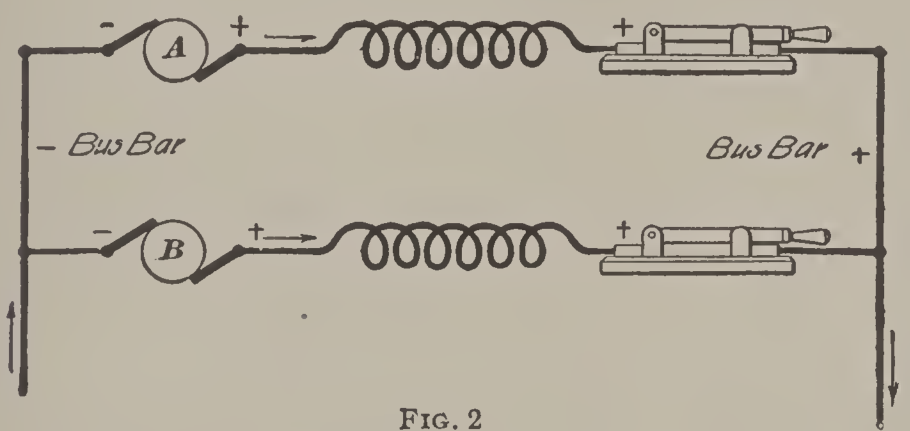


FIG. 2

half the current required by a certain load. As long as the two machines generate exactly the same voltage, they will continue to share the load equally; but if the voltage of one, say *A*, drops slightly, owing to reduced speed or other cause, that machine will at once cease to furnish its full share of the load, thus throwing more than one-half the load on the other machine *B*. Both machines being series-wound, the field of *A* will be weakened, thus still further decreasing its voltage, and the field of *B* will be strengthened until soon *A* will be overpowered, its current reversed, and it will be run as a motor with its direction of rotation reversed. This may result in considerable damage. The action of the two or more series machines connected as described in parallel, will, therefore, be very unstable.

4. Equalizer Connection.—The unstable condition just referred to can be remedied by connecting the inner ends of the series-fields of the two machines—that is, the ends connected to the dynamo brushes—by a low-resistance conductor, commonly called an **equalizer.** Fig. 3 shows

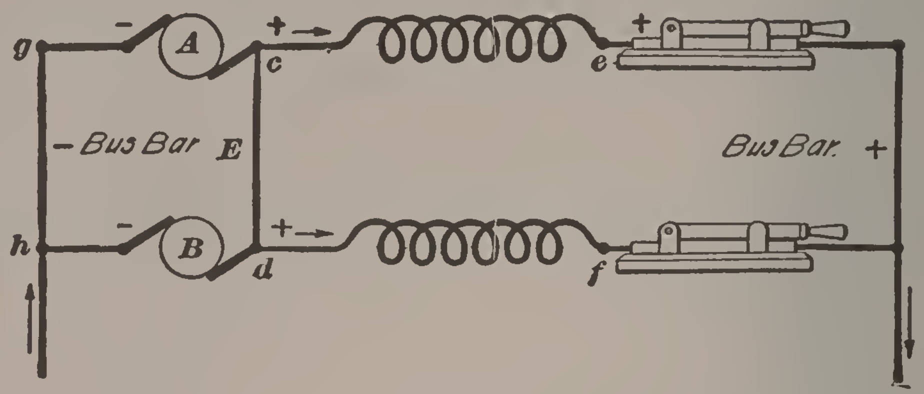


FIG. 3

the same connections as Fig. 2, except that an equalizer *E* has been added connecting the points *c* and *d* where the series-coils are attached to the brushes; *e* and *f* are the positive terminals of the machine. If, for any reason, the machine *B* at any time delivers a greater current than *A*, part of this current will flow to the + line through the coil *d f*, and part will take the path *d–c–e* through the series-field coil *c e* of machine *A*. The result is that part of the current delivered by *B* helps to keep up the field excitation of *A*, thus bringing up its voltage and equalizing the load between the machines. On the other hand, if *A* for any reason delivers the greater current, part of its current will flow through the path *c–d–f* and strengthen the field of *B* in the same manner.

SHUNT GENERATORS IN PARALLEL

5. Connections for two shunt generators are shown in Fig. 4. The usual arrangement is to use double-pole single-throw switches instead of the single-pole switches *M, N* and *M′, N′* shown here for sake of clearness of diagram.

If these two machines were operating in parallel, each supplying one-half the required current and one, say *A*, owing to a speed drop or any other cause, should reduce its voltage, and fail to supply its half of the current, more than

one-half the load would then be thrown on *B*. As the load on a shunt generator decreases, its voltage rises; and as the load increases, the voltage falls; therefore, the tendency would be for the voltage of *A* to increase and for *B* to decrease until the two were again equal. Shunt generators are, therefore, well adapted for parallel operation.

6. Starting Shunt Generators in Parallel.—All switches should be open while the machines are standing idle. In starting, both generators, having their switches still open, may be brought up to full speed if desired. One machine, say *A*, Fig. 4, is first built up and thrown into cir-

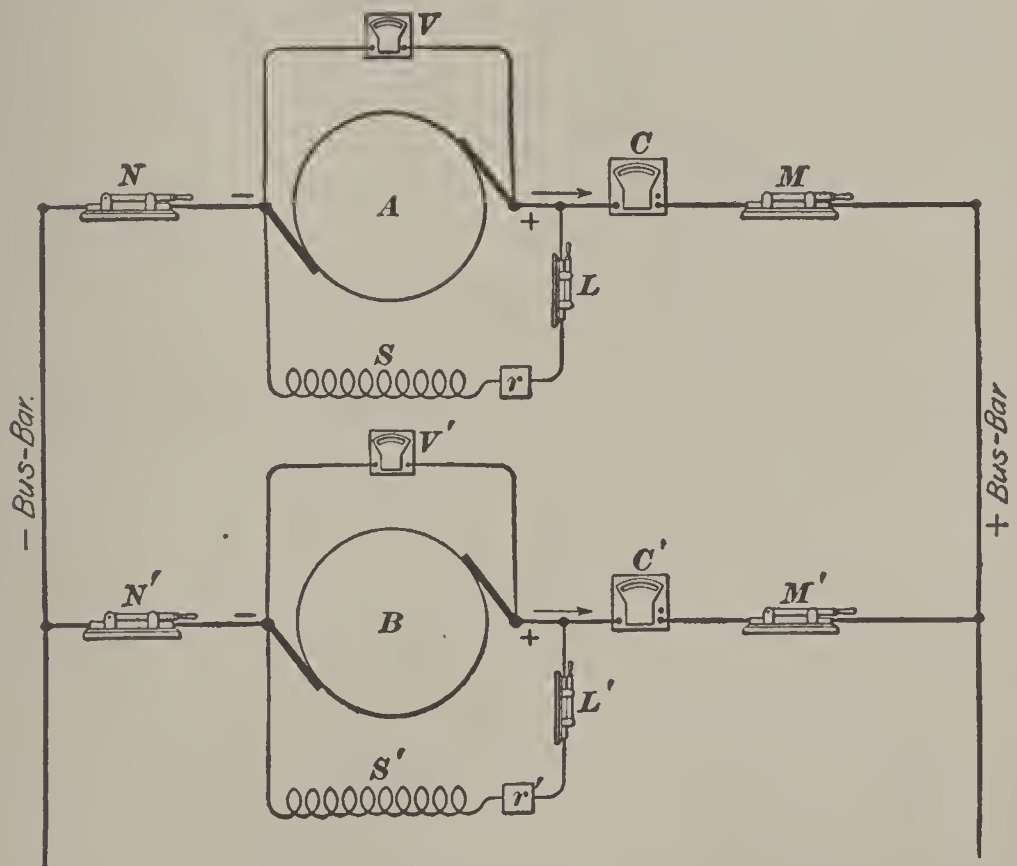


FIG. 4

cuit as follows: Close its field switch *L* and adjust its field strength by means of rheostat *r* until the voltmeter *V* indicates the proper electromotive force; close the main switches *M*, *N*, and machine *A* will then supply all the current, if it is capable. Now, close the field switch *L′* of machine *B* and adjust the rheostat *r′* until the voltmeter *V′* indicates 1 or 2 per cent. higher electromotive force than voltmeter *V*, and then close the main switches *M′*, *N′*. The two machines, if of the same capacity, should then each

supply very nearly the same current, as indicated by the ammeters C, C'. The division may be made as desired by adjusting one or both rheostats r, r'.

If the shunt field of the second machine is connected directly across the line, it will build up much more rapidly when its field switch is closed, because its field is then subjected to the full electromotive force of the other machine.

Any number of shunt generators may thus be operated in parallel, each succeeding one being started and thrown into circuit by the process described for machine B.

COMPOUND-WOUND GENERATORS IN PARALLEL

7. Since a compound-wound generator is a combination of a series and a shunt generator, the arrangement for parallel

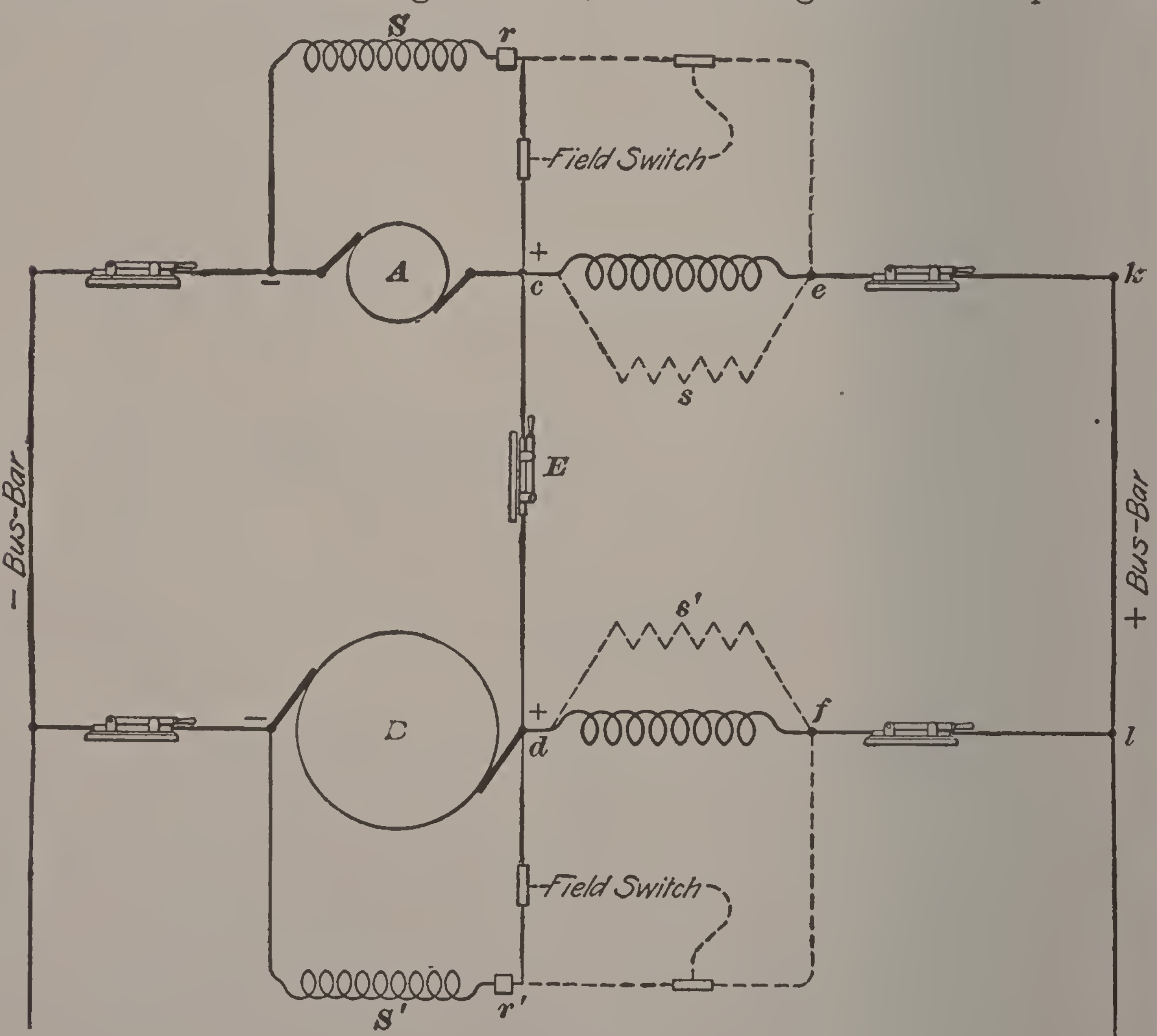


FIG. 5

running of such machines is a combination of the two preceding ones. The connections are shown in Fig. 5, where

the parts are lettered as in the two preceding figures. A switch E has been here added to the equalizer.

The machines are usually first adjusted separately by means of the shunts s, s' around the series-fields, so that at the same proportion of its load each will give as nearly as possible the same voltage, that is, the voltages must be made to agree at no load and at full load and they must also agree as nearly as possible at one-fourth load, one-half load, three-fourths load, etc. The machines need not necessarily be of the same capacity. The figure shows two methods of connecting the shunt field, one, known as **short shunt,** directly across the brushes, as shown by full lines, and one, known as **long shunt,** across the machine terminals, as shown by dotted lines $r e$ and $r' f$. It makes little difference which method is used.

In Fig. 5, there are two paths for current to pass from the positive brush of either machine to the positive bus-bar; one through its own series-field and one through the equalizer and the series-field of the other machine. If the resistance of the equalizer were zero, it is evident that the division of the current from either positive brush through the two paths would be inversely proportional to the resistance of the paths, that is, the path having the higher resistance would carry the smaller current. The division of the current between the two series-fields may, therefore, be made as desired by adjusting the resistance of one or both paths c–k and d–l.

8. Adjusting the Division of Load.—Suppose that two generators A and B, Fig. 5, of unequal capacities are to be adjusted so that they will share the load at all times very nearly in proportion to their total capacities. The compounding of each machine is first adjusted, as explained in Art. **7,** by adjusting its series-shunt s or s'. If when the two are connected in parallel one of them, A, supplies more than its share of the current, the resistance of the path c–k through the series-field coil of A should be increased until the division of the load is correct. The resistance of the series-field coil of a generator is usually very small, so that only a very slight addition will be needed in any case. The necessary

resistance may be obtained by using a longer lead between e and k or possibly by inserting iron or German-silver washers under a terminal lug. It is useless to try to adjust the division of load by adjusting the series-field shunts s, s', for when the machines are connected in parallel, adjusting either shunt affects both machines alike. The remedy for improper division of load in such cases is to insert a very slight resistance in series with the series-field coil of the machine taking more than its share.

For the most successful parallel operation, generators should be of the same design and construction and should possess as nearly as possible the same characteristics; that is, each should respond with the same readiness, and to the same extent, to any change in its field excitation. Any number of such machines may be operated in parallel.

9. The usual practice is to connect the equalizer and the series-field to the positive brush, though this is not necessary;

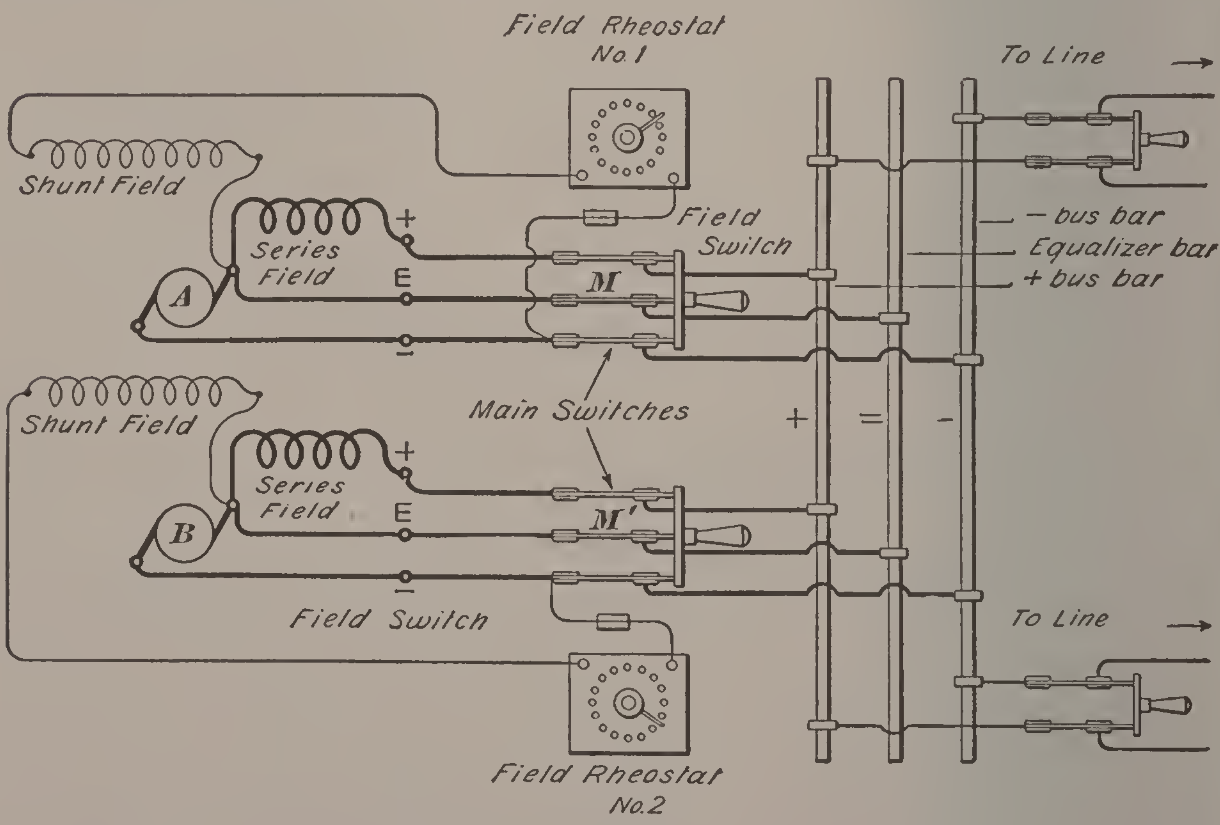


FIG. 6

they must, however, both be connected to the same brush. The resistance of the equalizer should be as low as possible and it must never be greater than the resistance of any of the leads from the generators to the bus-bar; that is, ek or fl, Fig. 5.

In some cases, the equalizer wire is run directly between the machines; but often in lighting or small railway stations, a third wire is run to the switchboard and there connected to an equalizer bar, as shown in Fig. 6, which represents a very common arrangement, triple-pole switches *M*, *M′* being used, the two outside blades being for the + and − leads, respectively, and the middle blade for the equalizer. There is a difference of opinion as to whether it is better to run the

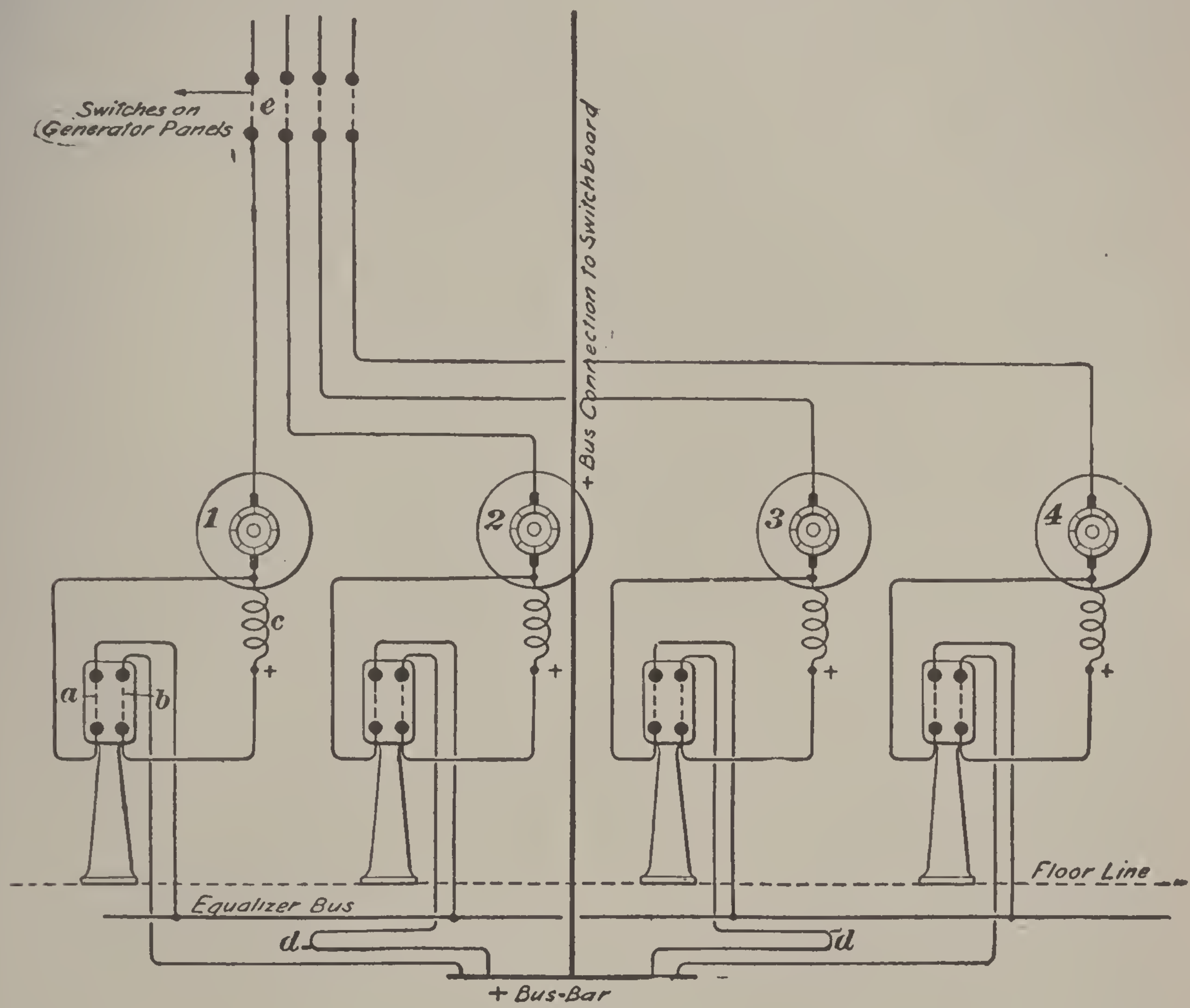


FIG. 7

equalizer to the switchboard or to run it directly between the machines, as in Fig. 5; but the most recent practice favors running it directly and placing the equalizer switch near the machine. This undoubtedly shortens the connections and permits better regulation. In such cases, the equalizer switch is usually mounted on a stand near the machine.

10. In some railway plants, where large generators are used, the main switch *b*, Fig. 7, is placed on the stand near the machine, alongside the equalizer switch *a*. These two

switches are at practically the same potential, and there is no objection to placing them near each other. In case this is done, one of the bus-bars, together with the equalizer bus, is placed under the floor near the machines. This shortens the connections considerably and makes the equalization of the load closer. It also simplifies the switchhoard connections and avoids crowding on the generator switchboard panels.

In Fig. 7, the main connections only have been shown, the shunt-field coils and all minor connections being omitted. The + leads from all the machines connect to the + bus-bar under the floor. If the machines are of equal capacity, these leads should all be of the same length in order to secure close equalization. In the case of machines *2* and *3*, the leads are doubled back as shown at *d* in order to make them of the same length as those from the more distant machines.

11. Starting Compound-Wound Generators in Parallel.—The general method of starting any machine, say *1*, Fig. 7, and throwing it in parallel with others already running is as follows: See that all switches on the generator panel of the machine are open; then bring the generator up to speed. Now, close the equalizer switch *a*, the + switch *b*, and lastly the shunt-field switch on the generator panel. As the series-coils of all the machines are in parallel, some of the current from the other machines will flow through the series-field of machine *1*, causing it to pick up rapidly; and since its shunt-field circuit is also closed, the machine will soon come up to full voltage. Adjust the voltage by means of the shunt-field rheostat until it is 1 or 2 per cent. higher than that of the other machines and then close the negative switch *e*, thereby completing the operation.

This method of procedure applies to the case where the +, −, and equalizer switches are independent of one another, as is usually the case in modern installations. When triple-pole switches are used, as in Fig. 6, all three must, of course, be closed together after the machine has been allowed to pick up its field and has had its voltage adjusted. After throwing

a machine in parallel, its load is adjusted by varying the field excitation. In case the machine is provided with a circuit-breaker, as is nearly always the case on modern switchboards, the circuit-breaker should be closed before the main switch, so that, if any rush of current occurs when the main switch is closed, the circuit-breaker will be free to act and disconnect the machine.

12. Main and Equalizer Cables.—In connecting the machines to the switchboard, cables of ample capacity should be used. For most cases, it will be sufficient to allow from 1,200 to 1,500 circular mils per ampere. Sometimes, an allowance as low as 1,000 circular mils per ampere is made, but the better practice is in favor of a more liberal cross-section. For very large currents, it is advisable to use two or three cables in parallel rather than a single large cable, as better radiating facilities are thereby provided. The cables leading to the equalizer bus should be of the same size as the main cables.

ALTERNATING-CURRENT MACHINERY

ALTERNATORS IN COMBINATIONS

13. As a rule, alternating-current machinery does not require as much care and attention as direct-current machinery. Many suggestions made for selecting direct-current machines, and nearly all the remarks relating to their installation, apply with equal force to alternating-current machines. Starting or stopping a single alternator with its exciter, is usually a very simple matter; but these machines are frequently required to operate in combination, which necessitates special consideration.

ALTERNATORS IN SERIES

14. Alternators cannot be run in series unless their armatures are rigidly connected by being mounted on the same shaft, so that the electromotive forces generated by the two machines will be equal and in synchronism. But this method is

obsolete, as high pressures can more conveniently be generated either with a single alternator or with an alternator and transformers.

ALTERNATORS IN PARALLEL

15. Alternators can be operated in parallel, although such operation is, as a rule, somewhat troublesome. This is especially the case if they are very different in size and design. They are usually connected to bus-bars through intervening main switches in much the same way as direct-current machines. If the alternators are compound wound, equalizing connections should be used; but many are operated with a separately excited field only, and no equalizing connection is necessary, the whole scheme of connection corresponding more nearly to the running of shunt-wound machines in parallel.

In order to operate alternators successfully in parallel, it is necessary that the electromotive forces developed by the two machines have the same *frequency* and are *in phase,* or *in step,* with each other. Two alternators have the same **frequency** when they reverse their polarities at the same instant. They are said to be **in phase** when the terminals are alive with positive or negative potential at the same instant. Clearly, it is not sufficient that the polarities change at the same instant, if they are not in phase; that is, if corresponding terminals have not the same polarity. Alternators are in **synchronism** when their currents have the same frequency and are in phase with each other.

16. Synchronizing.—The state of synchronism may be ascertained by means of what are called **synchronizing lamps** connected as shown in Fig. 8, where *T, T′* represent small transformers having their primary coils connected to the alternators, similar terminals *1, 1′* being connected to similar sides of the machines. The secondary coils are connected in series through a pair of lamps *l, l* and a plug switch *m*. Suppose the two alternators to be operating at the same frequency and in phase and consider the instant

when the pressures between the alternator leads are maximum for each machine, tending to cause a maximum current to flow through the transformer primaries from *1* to *2* and from *1'* to *2'*, respectively. This will cause maximum pressures to be set up in the secondaries tending to force current from *4* to *3* and from *4'* to *3'*, respectively; but, as these pressures are opposed to each other in the secondary circuit, as shown by the arrows, no current will flow and the lamps will be dark. If the currents are of the same frequency but opposite in phase, the current from *1* to *2* will be a maximum at the same time as

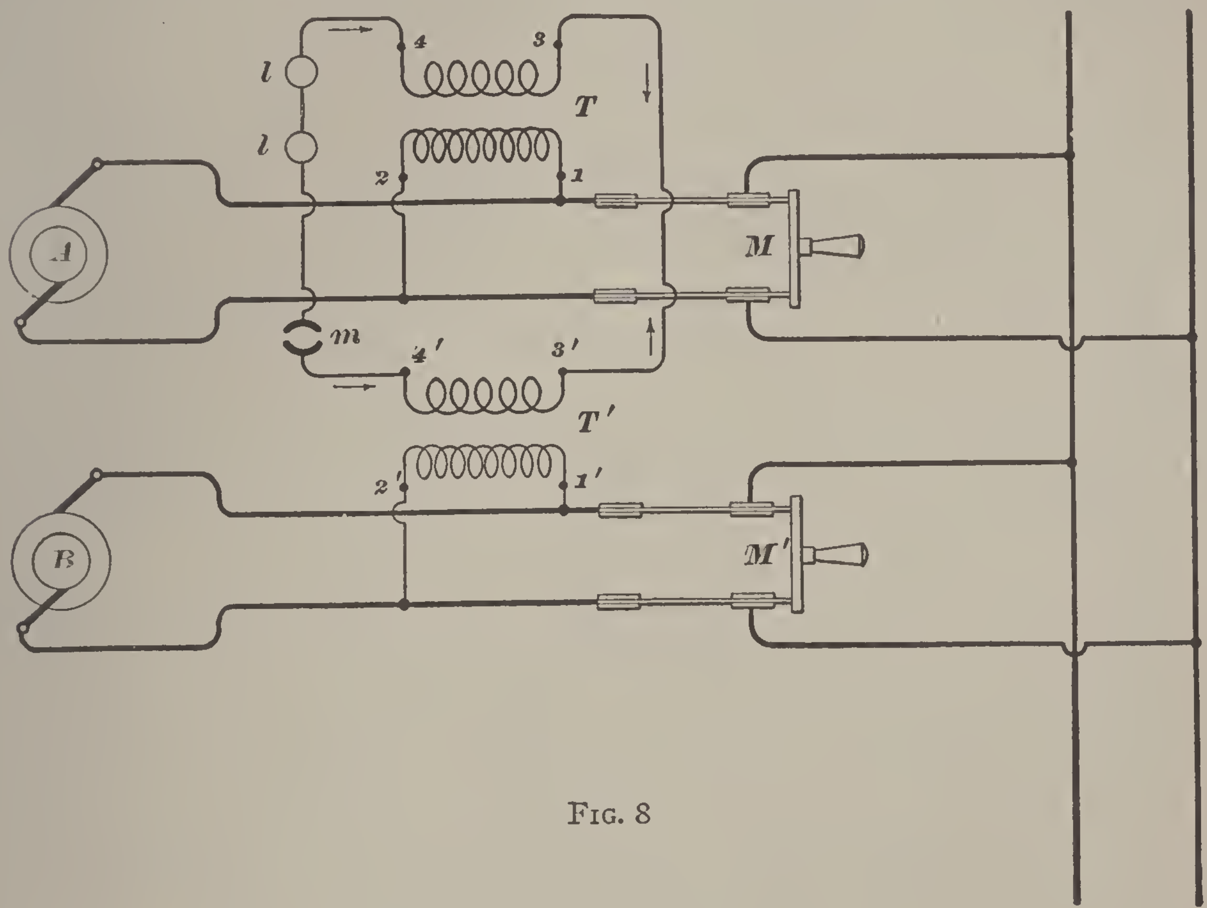


FIG. 8

that from *2'* to *1'*. This will cause pressures to be set up in the secondaries tending to cause current to flow from *4* to *3* and from *3'* to *4'* at the same instant; that is, the currents in the secondaries will now be in the same direction and the lamps will burn at full brilliancy. The one instant taken is illustrative of what occurs every instant throughout a cycle. If the currents are of the same frequency and in phase, the pressures of the two secondary coils will neutralize each other and the lamps will be dark; if the machines are exactly opposite in phase, the secondary pressures will supplement

each other and the lamps will glow at full brilliancy. As the machines approach synchronism, the lamps will become alternately light and dark, the periods becoming longer and longer as the synchronism becomes more perfect.

17. The process of starting an alternator and connecting it in parallel with one or more others already in operation is as follows: Suppose machine *A*, Fig. 8, to be running at full speed and voltage. If machine *B* is now started and the plug is inserted at *m*, the lamps will at first rapidly fluctuate in brightness, but as *B* approaches synchronism with *A*, the fluctuations will become slower. When they have become as low as one in 2 or 3 seconds, the main switch M' is thrown in at the middle of one of the beats when the lamps are dark. In some cases, the connections are so made that the lamps are bright when synchronism is attained. It is evident that this could be done by reversing the connections of one of the transformers. Whether the state of synchronism will be indicated by light or dark lamps depends simply on whether the transformer secondaries are connected so as to assist or to oppose each other.

18. Synchronizing Two-Phase and Three-Phase Machines.—If one phase of a two-phase or of a three-phase alternator is in synchronism with a corresponding phase of another alternator, the other phases will be in synchronism —provided, of course, that the machines are properly connected. Synchronizing circuits are, therefore, connected to only one phase of such alternators. But to insure that the connections are correct it is well temporarily to connect a pair of transformers across the other phases. For example, on a two-phase machine, an arrangement similar to that shown in Fig. 8 should be made for each of the phases, and when the connections are right and the machines are in phase, each set of phase lamps will be dark or light, as the case may be, at the same instant, showing that both phases are ready for parallel operation. After it is known that the connections are all right, the temporary pair of transformers may be removed and only one pair used.

19. Fig. 9 shows a common scheme of connections used for synchronizing three-phase alternators with lamps. In this case, the connections are shown for three machines, each machine being provided with its plug receptacle *p*. The primary coil of one small transformer *t* is connected across two phases of the main bus-bars, and that of the other *t'* across the synchronizing bus-bars, through which connection can be made to the same phase of any one of the machines by inserting a plug in the proper receptacle. For example,

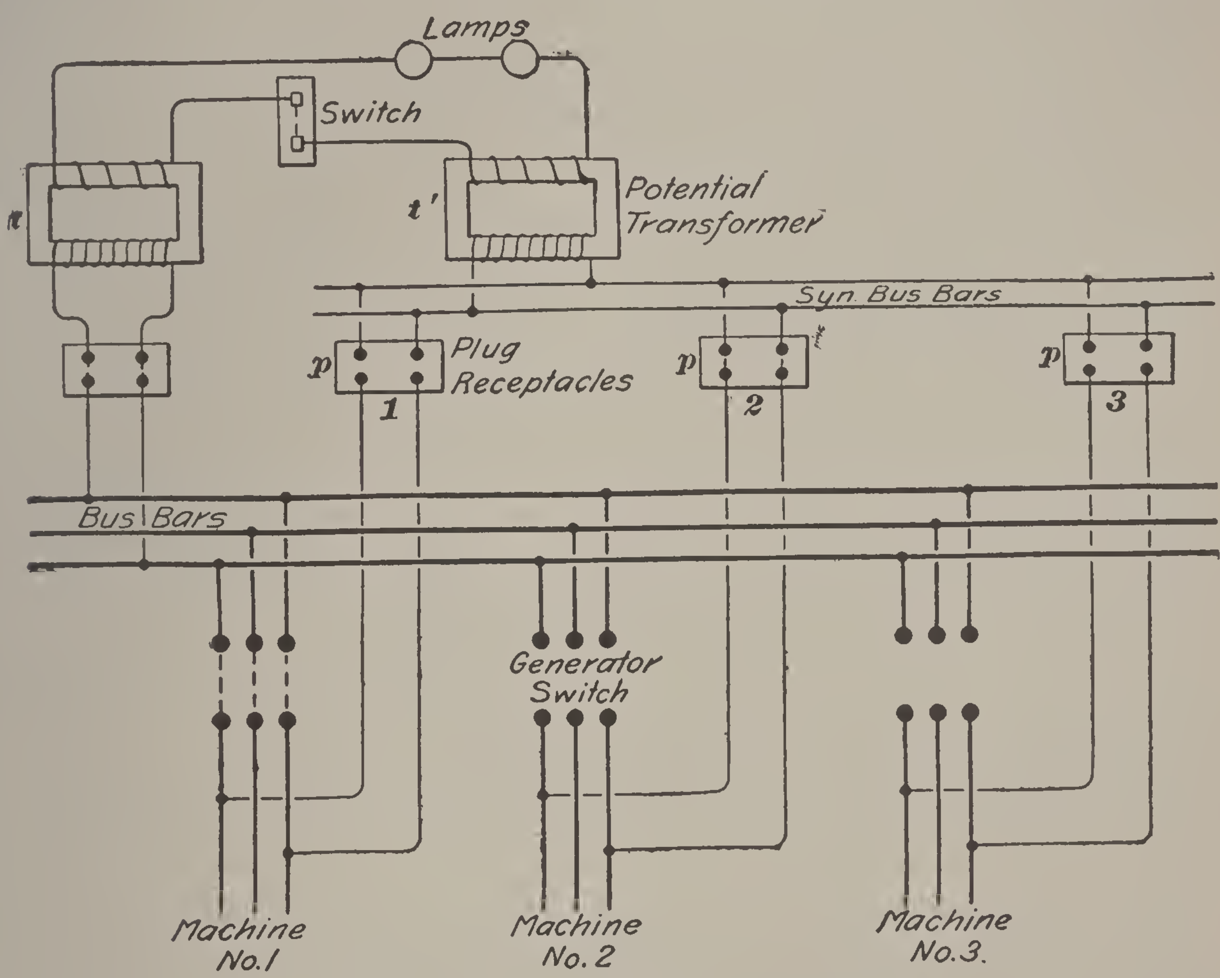


FIG. 9

suppose that the main switch of machine *1* is closed, as indicated by the dotted lines, and that it is desired to operate machine *2* in parallel with *1*. Machine *2* should first be brought up to speed and a plug inserted in receptacle *2*, thus connecting *t'* to the machine. Synchronism is here indicated when the lamps burn to full brightness; hence, the generator switch of machine 2 will be thrown in when the lamps are at the middle of a beat and at full brightness. The same arrangement can be used for synchronizing with

dark lamps, the only change being that the synchronizing plug then will be cross-connected, thus making the transformers oppose each other. With alternators built to generate a low voltage, as is sometimes the case when they are used in connection with step-up transformers or for low-voltage work, it is not necessary to use transformers t, t'; the terminals of the synchronizing circuit may be connected directly to the machines or bus-bars and a sufficient number of lamps used in series to stand the maximum voltage applied to them.

20. Synchronizing Instruments.—The use of lamps, as already explained, for indicating synchronism has been very common; but for large units this plan is not entirely satisfactory, because they do not indicate slight phase differences, which may cause large cross-currents to flow when the machines are switched together. A voltmeter is sometimes used in place of the lamps and the connections are so made that when the machines are approaching synchronism the voltmeter needle is near the middle of the scale, where it is very sensitive to slight differences in phase of the alternators. Synchronism indicators, synchronoscopes, and various other devices are also in use. There are many possible arrangements and modifications of connections, but the principles involved are the same in all and the object in all cases is to avoid throwing the machines together at the wrong time.

21. Alternators running in parallel will hold each other in step, and in doing this local or cross-currents may flow from one machine to the other. The division of the load cannot be regulated by adjusting the field excitation, as in the case of direct-current dynamos in parallel, but must be made by adjusting the engine governor. Adjusting the field excitation of alternators results only in changing the amount of local current flowing between the two machines and this should be made as small as possible; that is, the sum of the currents delivered by all the alternators should be made as nearly as possible equal to the total current supplied to the

line. The output of each machine will depend on the energy supplied to it by the engine. The distribution of the kilowatt load among the alternators is dependent on the relative phase positions of their rotating parts. Alternators in parallel must run in synchronism, yet it is possible by increasing the energy supplied to the prime mover of one alternator to force temporarily the rotating parts of that alternator ahead of the others in relative phase position. The alternator will then take on a greater share of the total load. Prime movers with governors that may be adjusted while the machines are running are used for the control of the load division between alternators in parallel. Setting the governor so that the prime mover takes more energy causes its alternator to pull ahead in phase and increases its load. Adjusting the governor so that the prime mover takes less energy causes its alternator to lag behind in phase and decreases its load. When cutting out an alternator, the governor is adjusted to decrease the load and then the switch is opened.

22. What has been said regarding the synchronizing of alternators applies also to synchronous motors and rotary converters; each must be synchronized before being connected with the alternating-current circuit.

23. Hunting of Alternators.—Alternators in parallel frequently give trouble from what has been termed **surging** or **hunting;** that is, the speed may vary periodically during certain portions of each revolution causing momentary cross-currents to flow. These currents may become so large as to seriously interfere with the voltage of the system. Alternators driven by large slowly moving reciprocating engines most often give trouble from this cause; the engine crank receives a certain number of impulses during each revolution and at each of these the angular velocity is increased a trifle. If the alternator to which the engine is connected has a large number of poles, a very slight change in angular velocity will produce a considerable phase difference. Alternators driven by steam turbines are less likely to hunt, because the angular velocity is more uniform.

Various devices have been used to overcome hunting, including improvements in engine governors, the use of heavy flywheels, the use of multiple-expansion engines, etc. Special windings or short-circuited conductors are sometimes used on the alternator pole faces so that suddenly shifting field magnetism caused by the surging current will induce currents that tend to retard or dampen such changes.

SWITCHBOARD APPLIANCES

FIELD RHEOSTATS

24. In order that the transmission system shall be under control and also that the condition of the lines, the amount of output, etc. shall be known, it is necessary to have various controlling, protective, and measuring devices in the station. These consist of *field rheostats; switches; fuses* and *circuit-breakers; ground detectors; lightning arresters; measuring instruments;* including voltmeters, ammeters, wattmeters, etc., and other auxiliary devices.

25. Little need be said regarding **field rheostats** in addition to what has already been given. They consist of a resistance so arranged that it can be cut *in* or *out* of a circuit by steps. The resistance material may consist of German-silver or iron wire, or sometimes of cast grids. Wire or strip resistance is usually wound or assembled on an insulating base of some sort and afterwards covered with an insulating and heat-conducting material. The total resistance should be about the same as that of the field to be controlled.

Unless the rheostat is very large, it is mounted either on the front or on the back of the switchboard. Very large rheostats are sometimes mounted at some convenient place some distance from the switchboard and are operated by small motors that are controlled from the switchboard. In any case, the rheostat handle is placed on the front of the board within easy reach of the attendant.

SWITCHES

LOW-TENSION SWITCHES

26. Probably the most important appliances on the switchboard are the **switches.** These must have ample carrying capacity and be capable of breaking the full-load current of the generator or circuit, without destructive burning or arcing. The style of switch used for any installation will depend on the voltage and current to be handled.

Plain knife switches are generally used for pressures up to 1,000 volts, and this style of switch with a broad separation of the blades and contacts has been used on pressures as high as 2,500 volts. For work of the latter class, however, it is preferable to use a switch of the quick-break variety (Art. **27**), and even for pressures as low as 500 volts, quick-break knife switches are often used. Fig. 10 shows a typical two-pole knife switch designed for front connections and provided with fuses. Fig. 11 shows a similar switch without fuses and intended for mounting on a

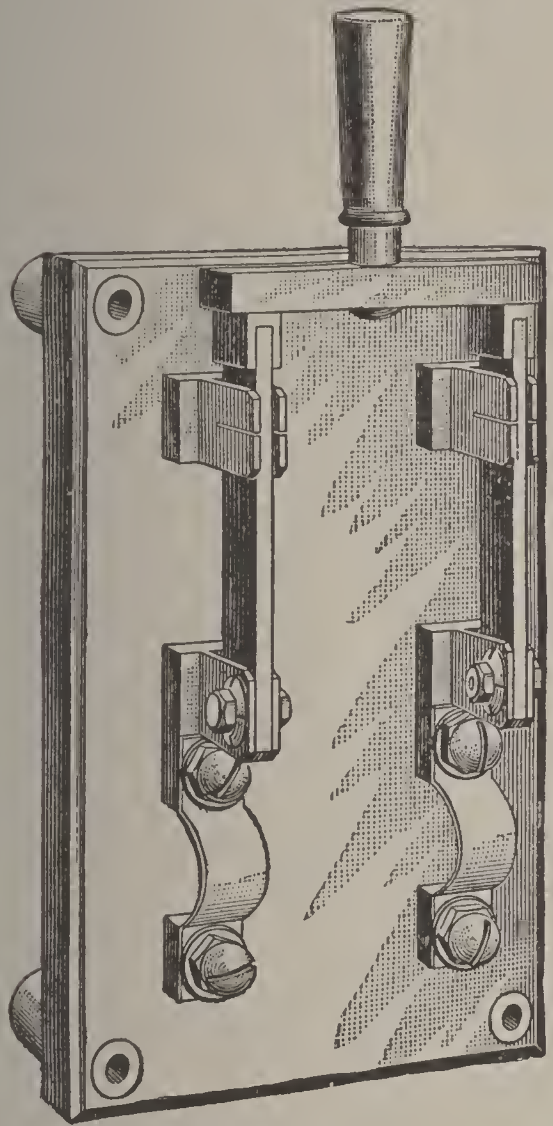


Fig. 10

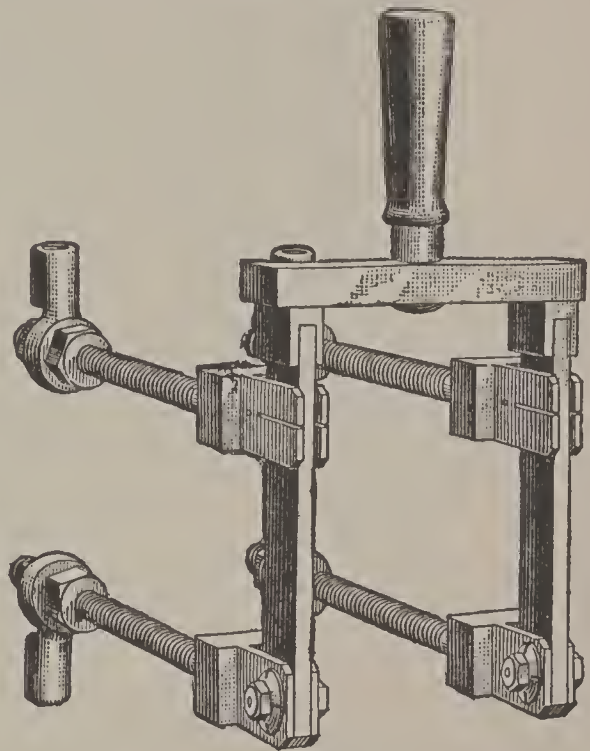


Fig. 11

switchboard. When the switch is opened, connection is broken between the two clips, on each side respectively, thus opening both sides of the circuit simultaneously. A knife switch should be mounted with the handle up when the switch is closed, so that, when open, the switch will not tend to fall closed.

27. Quick-Break Switches.—Fig. 12 shows a style of **quick-break switch** that has proved very successful and is suitable for pressures as high as 2,000 to 2,500 volts if the current is not large. The switch blade, of drawn copper, is

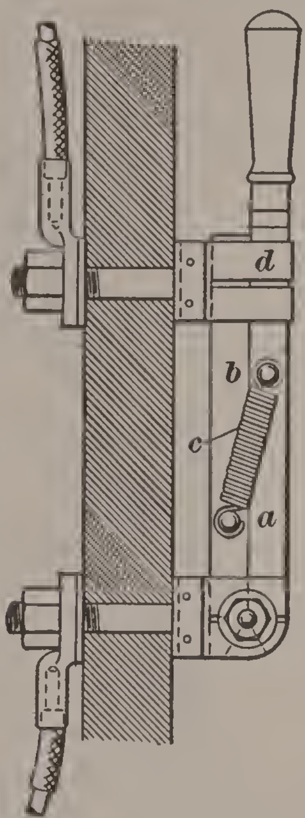


FIG. 12

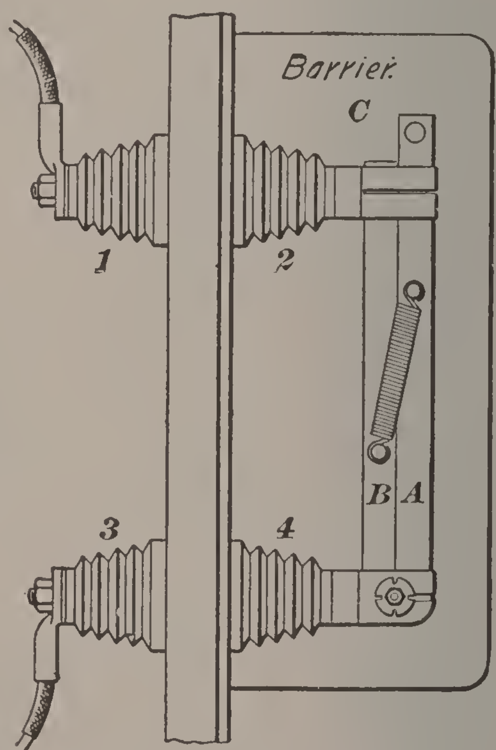


FIG. 13

made in halves, *a*, *b*, which are connected by two springs *c*, one on each side of the blade. When the handle is pulled out, the half *a* leaves the clip *d* and thus stretches the springs. When the bottom blade flies out, it leaves clip *d* very quickly, thus drawing out the arc and breaking it almost instantaneously.

HIGH-TENSION SWITCHES

28. Knife-blade switches of the types used for direct current are, without modification, suitable for use on low-tension alternating-current circuits. The current-carrying

capacities of small knife-blade switches are the same for alternating current as for direct current. In the medium and large sizes, however, the switches are likely to be heated more by an alternating current than by a direct current of equal amperage.

29. Oil Switches.—Knife-blade switches or air-break circuit-breakers are not suitable for use in high-voltage circuits on account of the long and dangerous arcs that are produced

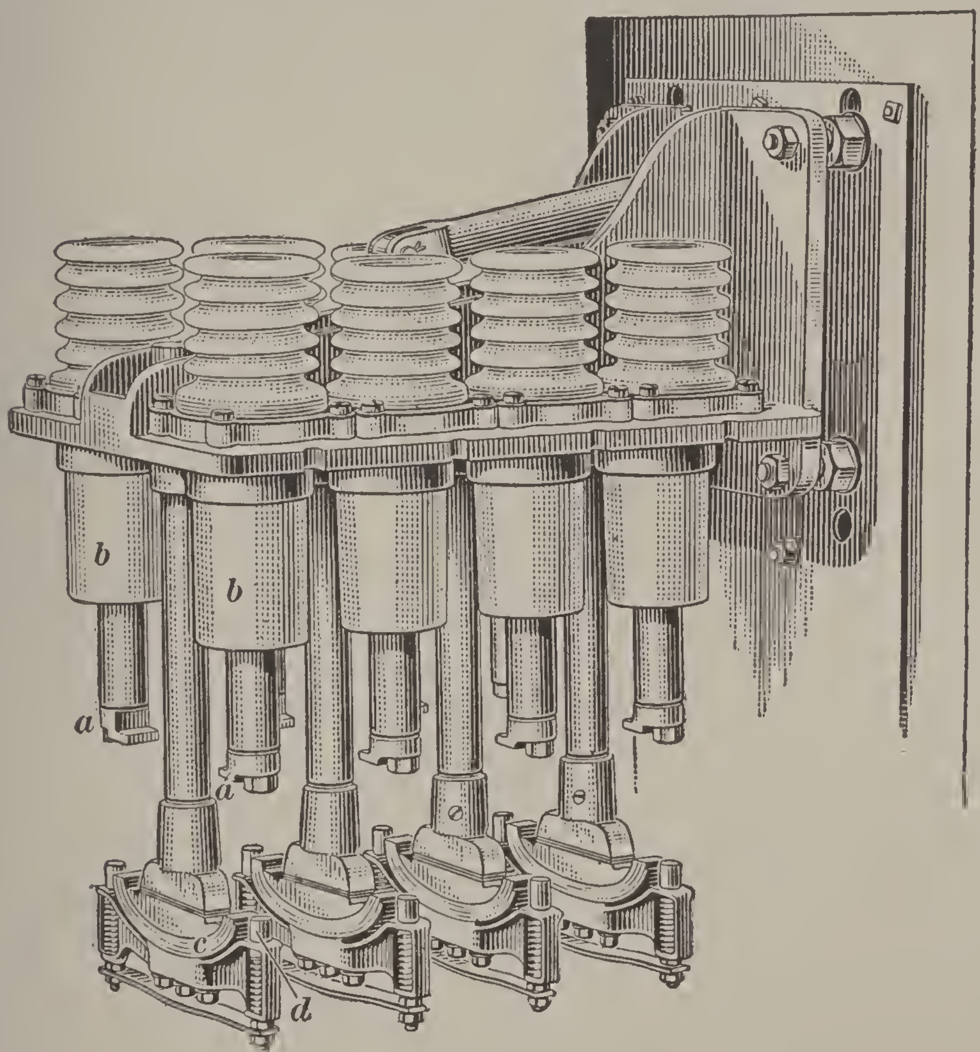


FIG. 14

when circuits carrying currents at high potential are broken in air. For such work **oil switches** are used. These are so designed that the point at which the electric circuit is made or broken is situated under the surface of a high-resistance oil contained in a closed vessel. The weight of the oil and its cooling effect combine to smother the arc formed, breaking the circuit, and the length of the arc is reduced to only a fraction of what it would be if the opening were in air. The oil wells are usually made of cast iron or sheet iron lined with wood.

30. On potentials of 4,000 volts or over, it is common practice to open each line of a circuit in a separate oil vessel, or in a separate compartment of one vessel, and to open each line simultaneously in two places, by arranging two sets of contacts in series. Fig. 14 shows a 15,000-volt, 300-ampere, two-phase, oil switch with the oil well removed. Leads are brought to each pair of fixed contacts *a* through porcelain bushings *b* set into the cast-iron cover on the under side of which the oil well is supported. Each movable contact consists of two parts, a main contact *c* of heavy sheet-copper brushes and a pair of auxiliary contacts *d* consisting of short, movable, copper cylinders held in place by helical springs. On opening the switch, the final break is at the auxiliary contacts, which take the arc. The movable contacts are carried on wooden rods, which are lifted by operating a system of levers known as a *link mechanism*. In Fig. 14 the switch is shown in the open position.

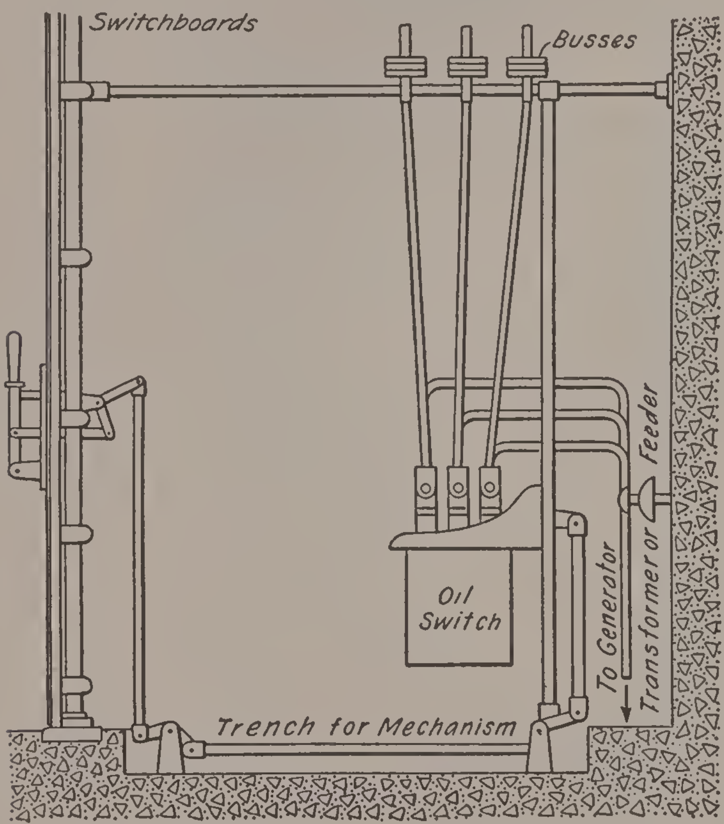


FIG. 15

Oil switches are operated manually, electrically, or pneumatically. Manually operated oil switches are suitable for use on circuits carrying moderate amounts of energy. They are operated by a handle connecting through a link mechanism to the vessel carrying the moving contacts. For switches mounted on the backs of the switchboard panels the linkage is very short. When it is preferred to place the switches farther away, the links are made longer and the direction of motion is changed by means of bell-cranks, as shown in Fig. 15, which shows oil switches operated by hand.

FUSES AND CIRCUIT-BREAKERS

31. Either fuses or circuit-breakers may be used to protect the generators or circuits from an excessive flow of current, due either to a short circuit or to an overload. Fuses are not used as much as they once were, as it has been found that circuit-breakers are more reliable. The circuit-breaker may be a separate device, or the main switch may be provided with an automatic tripping device that will open the switch when the current exceeds a given amount.

FUSES

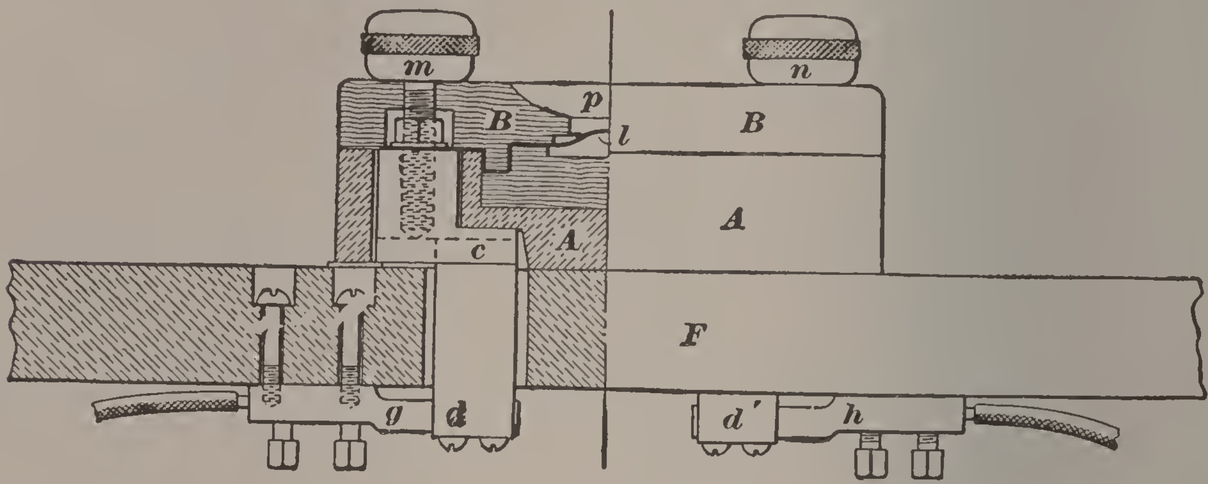
32. A **fuse** consists of a strip or wire of fusible metal inserted in the circuit and so proportioned that it will melt and open the circuit if the current for any reason becomes excessive. Fuses are often made of a mixture of lead and bismuth, though copper and aluminum are also used. Aluminum is used very largely for high-tension fuses.

For low-tension switchboards, plain open fuses may be used; but for high-tension work it is necessary to have them arranged so that the arc formed when they blow will not hold over. Moreover, it is necessary to have high-tension fuses arranged so that they can be renewed without danger to the switchboard attendant.

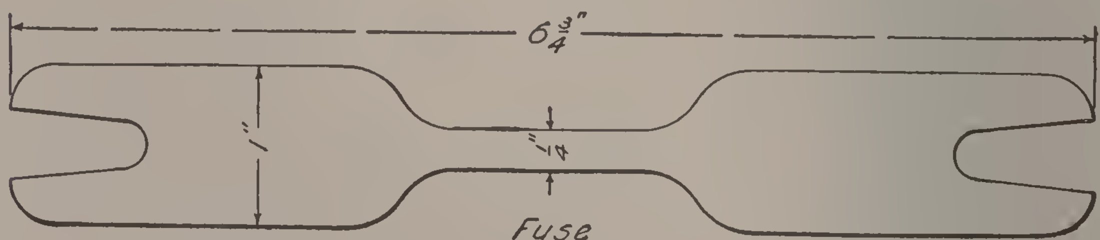
Fuses are still much used on alternating-current boards and also for protecting individual parts of direct-current circuits. The trouble and delay caused by the frequent blowing of fuses sometimes cause attendants to use a heavier fuse or a piece of copper wire, thus removing all the protection for which the fuse was installed. A fuse should be selected of such size that it will blow before any part of the circuit that it is designed to protect can be injured. If it be found that the proper size of fuse blows repeatedly, the circuit should be examined to find the cause of the trouble.

33. Enclosed Fuses.—Many types of **enclosed fuses** are available and some form of these should be used wherever there is any possible danger of fire.

34. Fig. 16 (*a*) shows a type of fuse block, half in section, used by the General Electric Company on alternating-current switchboards; (*b*) shows the shape of the aluminum fuse used in the block. The fuse holder is made in two parts, the lower part *A* being of porcelain and the upper part *B* of lignum vitæ. The lower part is provided with blades *c* that fit between the clips *d*, *d'* in the same way as the blades of a knife switch. These clips lie in slots in the marble board *F* and are connected to the line and generator by means of terminals *g* and *h*. By adopting this



(*a*)



(*b*)

Fig. 16

arrangement, the whole block may be detached from the board by simply pulling it straight out, thus pulling the blades out of the clips. The fuse is shown at *l*, and is clamped by means of the screws *m*, *n*. A vent hole *p* is provided in the lignum-vitæ cover, and the rush of air through this vent, together with the confined space, results in the suppression of the arc. This fuse block is suitable for currents up to 150 amperes at 2,500 volts. For higher pressures, fuse blocks are used in which the fuse is pulled wide apart as soon as it blows, thus breaking the arc.

CIRCUIT-BREAKERS

35. A **circuit-breaker** is essentially an automatic switch that opens the circuit whenever the current exceeds the allowable limit. It is therefore intended more as an automatic safety device than a switch for regularly opening or closing the circuit.

Circuit-breakers are made in great variety to handle currents varying from a few amperes up to several thousand; they are constructed for both alternating and direct currents. In nearly every case, they consist of a switch of some kind that is held closed against the action of a spring. The main current passes through an electromagnet or solenoid, and when the current for which the breaker is set is exceeded, this magnet attracts an armature or core and operates a trip thus allowing the switch to fly out. In some cases, the breaker opens both sides of the line, though often it is single-pole and opens one side only. A single example will show the general method of operation.

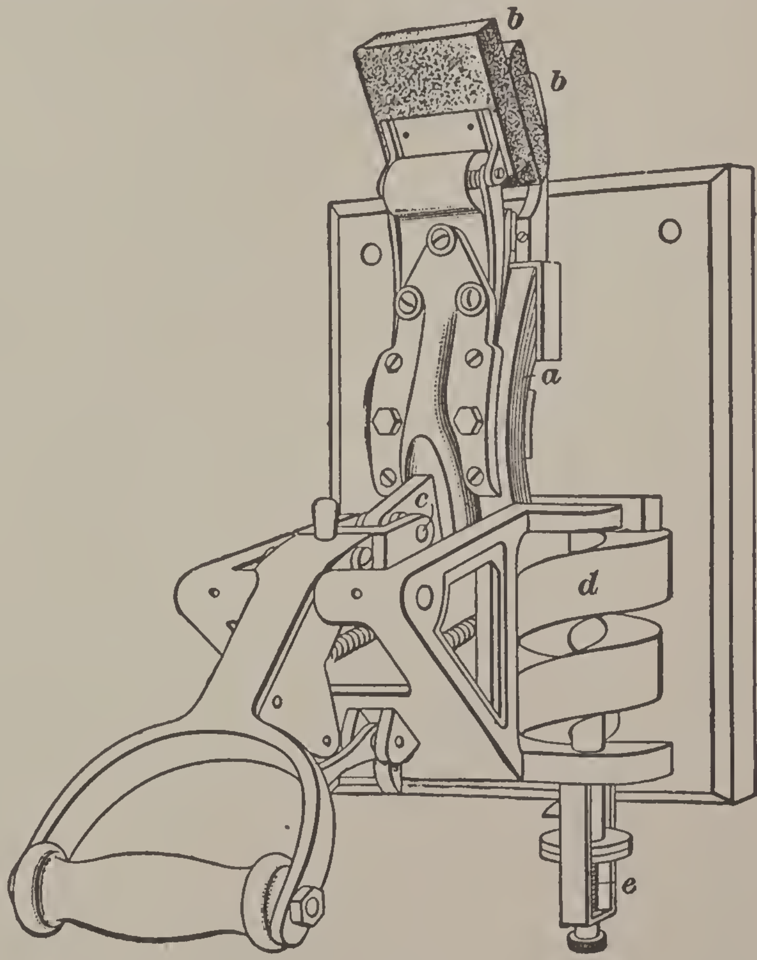


FIG. 17

36. In the single-pole, direct-current, overload circuit-breaker, Fig. 17, the main contact *a* is laminated and is pressed against the contact surfaces by means of the handle working through a togglejoint at *c*. The tripping coil is shown at *d*; and when the current exceeds the amount for which the breaker is set, the core inside *d* is suddenly drawn up, this striking a trigger and allowing the

breaker to fly out. The position of the core in *d* can be changed by adjusting screw *e*, thereby varying the current at which the breaker trips. Auxiliary carbon contacts *b*, *b* do not open until after the main contact, so that the burning action is confined to the carbon contact surfaces.

Many overload circuit-breakers are very similar in general appearance and operation to the type shown in Fig. 17, the main difference being in the arrangement of the tripping coil.

It has been suggested that for use in gaseous mines, switches, fuses, circuit-breakers, etc. be provided with gauze covers; this has been tried in some European mines, but it is not done in the United States.

GROUND DETECTORS

37. Ground detectors are used to determine whether or not a transmission line that should normally be insulated, is in contact with the ground or any conductor leading to the ground. A voltmeter makes a very good ground detector, because it not only indicates whether a ground is present, but by its deflection it shows whether the path of the current to ground is one of high or low resistance. Most ground detectors have a permanent ground, as indicated by *G* in Figs. 18, 19, and 20.

In order to indicate grounds, the voltmeter may be connected as shown in Fig. 18 (*a*). If the line *a* is grounded at *G′*, as indicated by the dotted line, no deflection will result when the switch blade *c* is placed on point *1*. If, however, the blade is moved to point *2*, current will pass from line *a* through the ground on the line, and the permanent ground *G* of the detector, to the voltmeter, to point *2*, and thence to the line *b*, thus completing the circuit. When a deflection is obtained on point *2*, it shows that line *a* is grounded; and when obtained on point *1* it shows that line *b* is grounded. Fig. 18 (*b*) shows an arrangement for connecting the ordinary voltmeter so that it may be used both to measure the line pressure and as a ground detector. When

the switch is in the position *1–1′*, the voltmeter *V* is connected directly across the line and gives the voltage on the system; when in the position *3–3′*, *V* indicates any grounds, such as *G″*, that may be present on line *b*; when in the position *2–2′*, *V* indicates grounds on line *a*, as at *G′*. It is

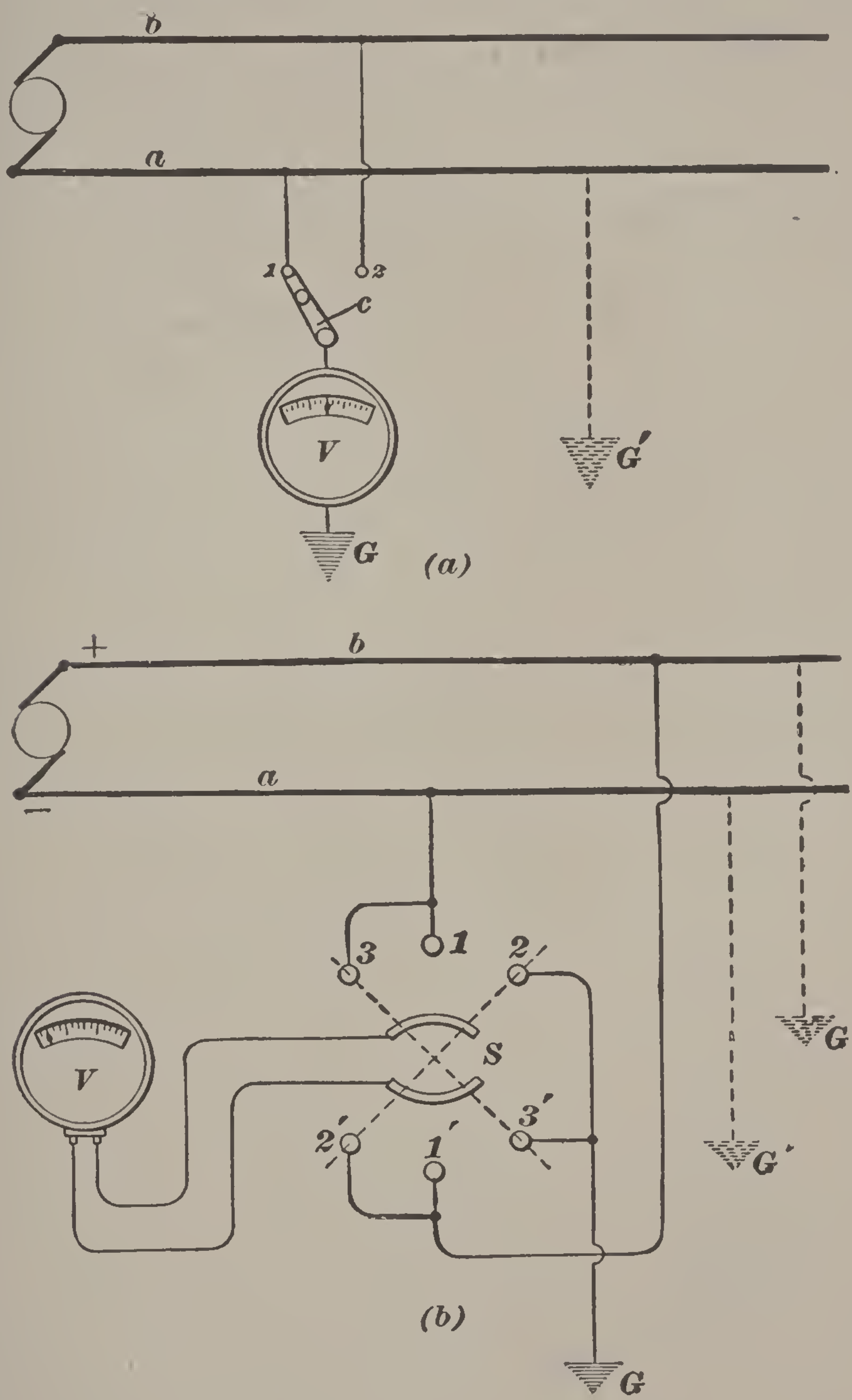


FIG. 18

evident that the needle will swing in the opposite direction for a ground on *a* than for one on *b* and also that the degree of the deflection will indicate whether the ground is of high or low resistance.

38. Another common arrangement for detecting grounds is shown in Fig. 19, where two incandescent lamps *c*, *d* are connected in series across the lines. The voltage for which these lamps are designed is equal to that of the dynamo, so that when the two are connected in series, they will burn dull red. From a point between the lamps, a connection is made to ground through a switch or push button *f*. If contact is made at *f* and there is no ground on either line, the brilliancy of the lamps will not be altered. If there is a ground on *b*, as indicated at *G′*, lamp *c* will burn brighter than *d*; or if the resistance of the ground connection is low, *c* will burn at full brilliancy and *d* will become dark.

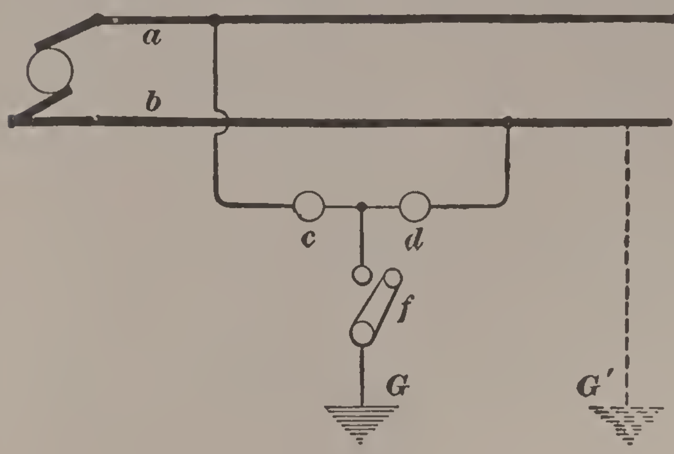


FIG. 19

39. The ground detectors just described apply more particularly to low-tension direct-current installations, but similar arrangements may be adapted to high-tension, alternating-current systems by using potential transformers. Fig. 20 shows one method that has been used in some cases on alternating-current switchboards. The regular voltmeter *V* with which the switchboard is equipped

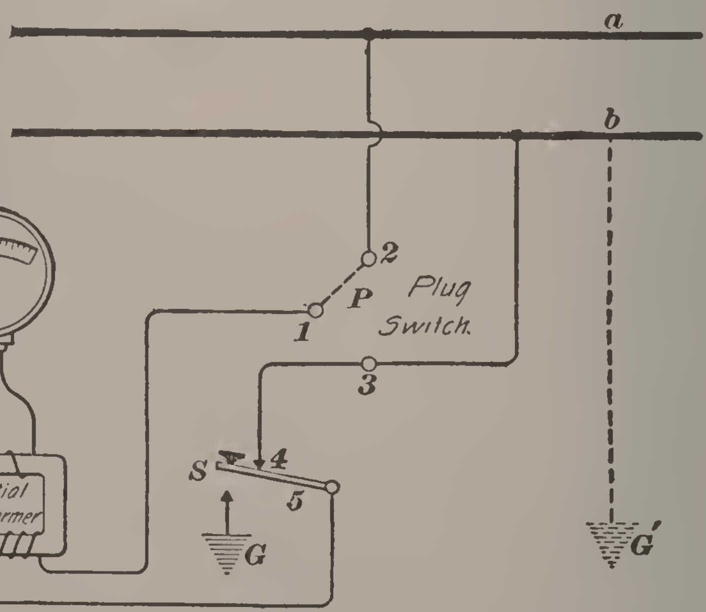
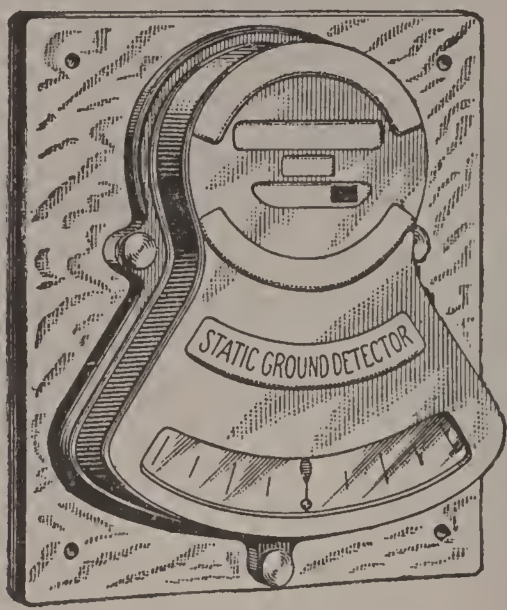


FIG. 20

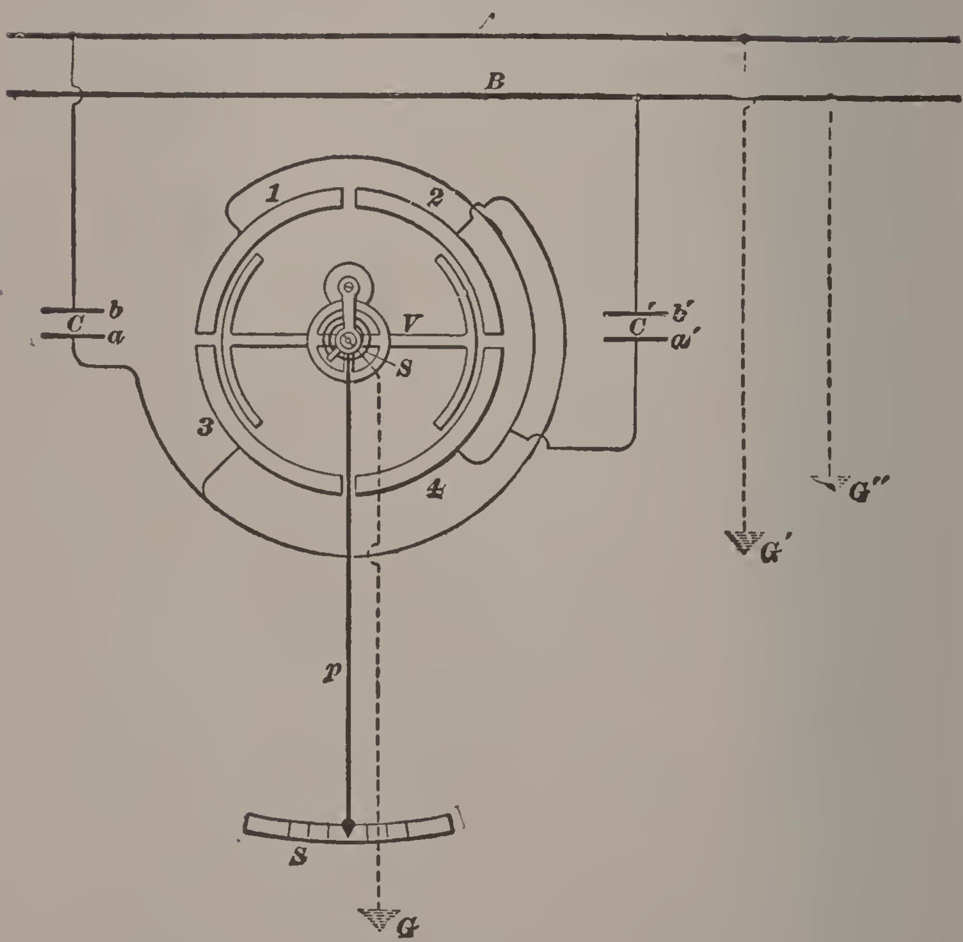
is here used also as a ground detector. *P* is a plug switch by means of which points *1* and *2* or *1* and *3* may be connected together. Under ordinary conditions, the plug is in *1* and *2*, thus connecting the primary of the potential transformer across the line, and *V* serves as an ordinary voltmeter. *S* is a key normally resting against *4*, but which may be depressed so as to connect one side of the line to ground through the transformer primary. If there happens to be a ground on the side *b*, as shown at *G′*, the voltmeter will give a reading when *S* is pressed. By placing the plug in points *1* and *3*, side *a* may be tested in like manner for grounds. When the key *S* is not pressed, *V* is connected as an ordinary voltmeter.

40. Electrostatic Ground Detectors.—Ground detectors operating on the electrostatic principle are much used on high-pressure alternating-current switchboards. They have the advantage that they require no current for their operation and hence may be left connected to the circuit all the time, thus indicating a ground as soon as it occurs. They also give an indication without its being necessary to make an actual connection between the line and ground as is the case with all the detectors previously described. Fig. 21 (*a*) and (*b*), respectively, shows the general appearance and illustrates the principle of a **Stanley electrostatic ground detector** especially adapted to high-pressure, alternating-current lines because the instrument is not in actual connection with either of the lines. The fixed vanes *1* and *4*, *2* and *3* are connected together in pairs, as shown, the two pairs being connected respectively to plates *a′*, *a* of two small condensers *b*, *b′*, which consist simply of two brass plates, mounted in hard rubber but separated from each other. Plates *b*, *b′* of the condensers are connected to the lines *A*, *B*. The movable vane *V* is connected to the ground and is held in the central position shown in the figure by means of small spiral springs *S*. To explain the operation, consider an instant when line *B* is positive. Then plate *b′* will be positive and a negative charge will be

induced on plate a', repelling an equal positive charge to plates *1* and *4*. At the same instant, line A and plate b will



(a)



(b)

FIG. 21

be negative, plate a positive, and plates *2* and *3* negative. If, at that instant, line B is grounded as shown at G'', connection through ground from G'' to G and thus to movable

vane V will make the potential of V positive, or the same as plates *1* and *4*, and V will therefore be repelled by plates *1* and *4*, and attracted by plates *2* and *3* because these two plates are negative. If, instead of a ground on B, line A is grounded as shown at G', V will be of the same potential as *2* and *3* and will be repelled by them and attracted by *1* and *4*. With B grounded, then, the pointer will swing to the right, and with A grounded, to the left.

Instruments of this kind can, of course, only be used in places where the pressure is fairly high, as the electrostatic forces produced by charges due to low pressures will not be large enough to operate an instrument unless it is made much too delicate to be of practical use in a light or power station. In most electrostatic detectors, the lines are connected directly to the fixed sectors *1*, *2*, *3*, *4* and the condensers C, C' are omitted.

PROTECTION FROM LIGHTNING AND STATIC CHARGES

41. Sources of danger to electrical equipments may arise outside the station and may cause great loss unless ample provision is made for protection. Among these may be mentioned danger from lightning, danger from static charges, or other effects commonly referred to as *static*, and danger from short circuits caused by either of the former. Damage from lightning occurs on systems having overhead lines, but static charges and the damage resulting therefrom can occur on systems having either overhead or underground lines.

PROTECTION FROM LIGHTNING

42. Lightning Arresters.—Differences of potential often arise between the atmosphere and the earth. These differences cause discharges of atmospheric electricity that, in seeking a path of low resistance to earth, frequently follow overhead electrical conductors into switchboards or dynamos where, unless proper precautions are taken, great damage may result. These precautions consist of furnishing a path

easier for the discharge to follow on its way to earth, than to go through the insulation of a machine or to arc across terminals on a switchboard. A device for diverting lightning discharges away from an electric circuit and guiding them to earth is called **a lightning arrester.**

43. A simple lightning arrester is shown diagrammatically in Fig. 22. A lightning discharge is generally *oscillatory* in character; that is, it alternates in direction, but the potential is greatest at the beginning and decreases gradually to zero. It will not pass through an inductive path if an alternative non-inductive path is provided for it. The choke coils *A*, *A*, therefore, act as an obstruction to the discharge, which prefers to jump across the air gaps *g*, *g* between plates *1*, *3*

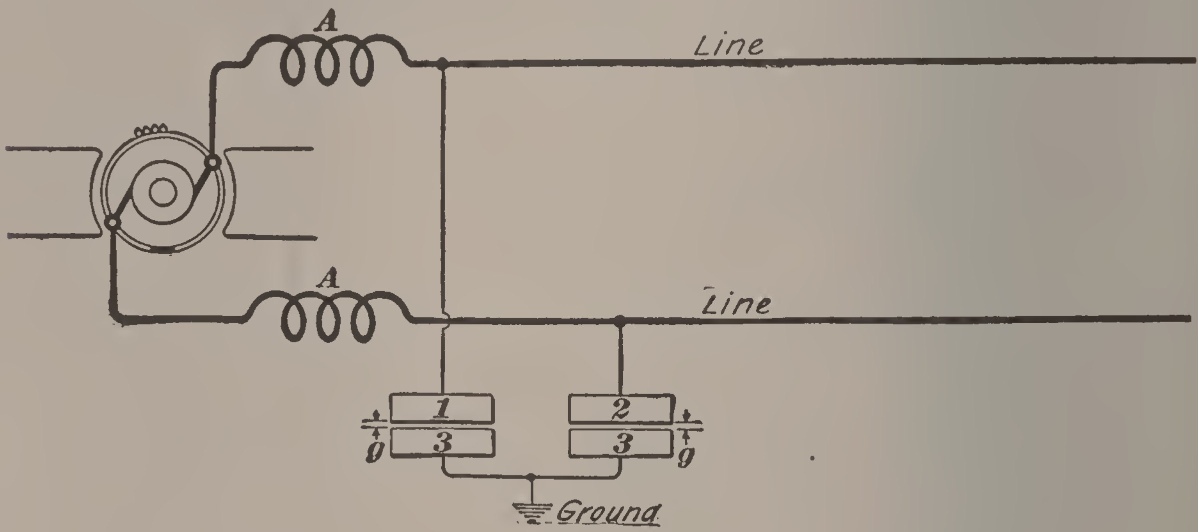


FIG. 22

and *2*, *3* and thence to ground. The air gaps *g*, *g* must be long enough so that the generator pressure will not cause the formation of arcs. A distance of $\frac{1}{32}$ inch should be sufficient for pressures up to 500 volts.

44. Suppression of Arcing.—With connections as shown in Fig. 22, a discharge from both lines at the same time should cause the formation of arcs across each gap. The current from the generator would follow these arcs and the machines would thereby be short-circuited. This large short-circuited current would melt the plates of the arrester and might damage the machine. The arc must, therefore, be suppressed as soon as the discharge has passed and the arrester must be left in condition for the next discharge.

This may be accomplished either by an automatic device that will lengthen the gap until the arc is broken; or by a magnetic field arranged to blow out the arc; or by causing the arc to be formed within a confined space so that it will be smothered; or by making the plates or terminals, between which the arc forms, of a non-arcing metal, the vapor of which forms a high resistance path.

45. Location of Lightning Arresters.—Lightning arresters should be placed not only at the power house, but at each place where discharges may work damage by passing to ground through insulation or apparatus. On long transmission lines, arresters are sometimes mounted on poles at regular intervals. Sometimes a separate barbed iron wire is strung along the tops of the poles and connected at frequent intervals to the ground. By this method, the discharges are carried to earth continuously and thus prevented from reaching a potential sufficiently high to work injury.

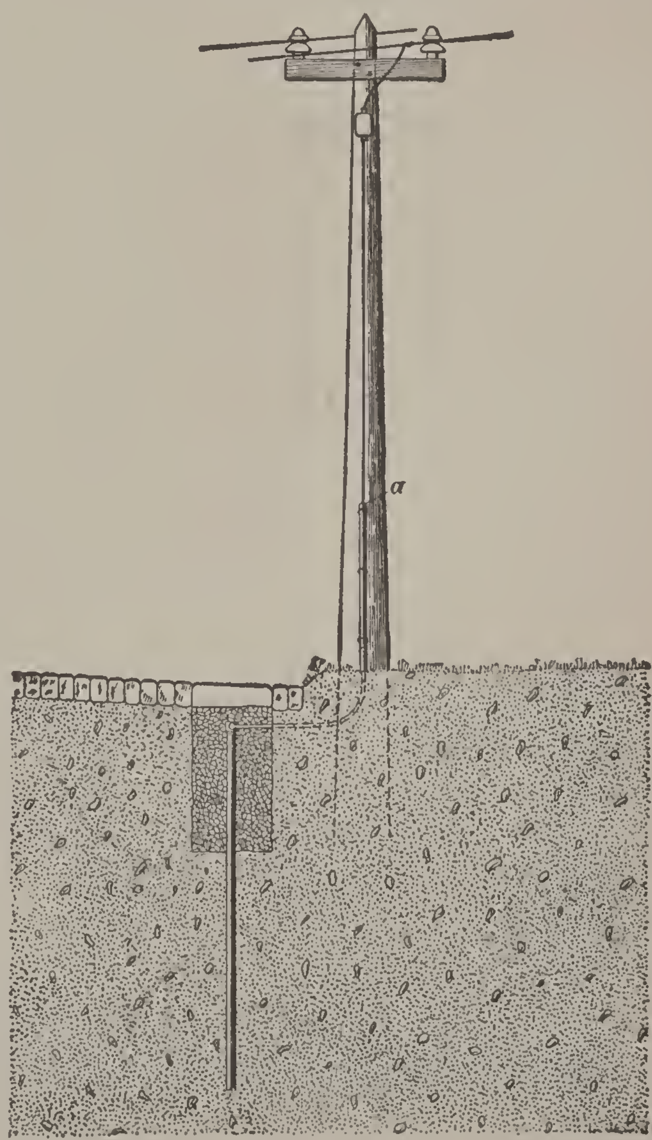


FIG. 23

46. Connections to Ground.—Unless the ground connections are good, arresters will be useless. The Westinghouse Company recommends a ground connection shown in Fig. 23. A galvanized-iron pipe is driven well into the ground and the top of it surrounded by coke, which retains moisture; the wire is run down the pole and connected to the top of the pipe as indicated. The wire is sometimes incased

in galvanized-iron pipe for about 6 feet from the base of the pole, and if this is done it is well to solder the ground wire to the top of the pipe at *a*. The following method of making the ground connections at the station is recommended: A hole is dug 6 feet square and 5 or 6 feet deep in a location as near the arresters as possible, preferably directly under them. The bottom of this hole is then covered to a depth of about 2 feet with charcoal or coke crushed to about pea size. On top of this is laid a tinned, copper sheet, about 5 feet square, with the ground wire (about No. 0 B. & S.) soldered completely across it. The plate is then covered with a 2-foot layer of coke or charcoal and the remainder of the hole filled with earth, running water being used to settle it. This will give a good ground, if made in good rich soil; it will not give a good ground in rock, sand, or gravel. Sometimes grounds are made by putting the ground plate in a running stream. This, however, does not give as good a ground as is commonly supposed, because running water is not a particularly good conductor and the beds of streams very often consist of rock. When lightning arresters are installed, all wires leading to and from them should be as straight as possible. Bends act more or less like a choke coil and tend to keep the discharge from passing off by way of the arrester.

47. Selection of Lightning Arresters.—Some arresters will work on either direct- or alternating-current circuits but, generally speaking, the arrester should be selected with reference to both the voltage of the circuit and the kind of current. The variety of arresters adapted both to direct and to alternating currents is too great to attempt their description here.

STATIC CHARGES

48. High-pressure systems are sometimes subjected to pressures very much higher than the normal by what are known as **static charges.** Any sudden change in the electromotive force is likely to cause these; as, for example, switching a high electromotive force on to a circuit, switching a transformer into circuit, etc. This effect is somewhat

similar to that caused by suddenly checking the flow of water in a pipe. If a valve be suddenly closed, the impetus of the water flowing in the pipe will cause the pressure to rise much above the normal, producing the well-known water-hammer effect. To guard against breaking down insulation by high static charges, devices very similar to lightning arresters are used. In fact, a number of large plants have their lines fully equipped with lightning arresters, even though the distributing lines are entirely underground and hence safe from lightning discharges. The lightning arresters are in such cases installed to protect the cables against abnormal pressures caused by the so-called static effects.

MEASURING INSTRUMENTS

49. Instruments for measuring electrical quantities are made in many forms and varieties. They all depend on reactions or heating effects caused by the passage of an electric current through some portion of the instrument. Commercial instruments may now be had, on which may be read at a glance and with great accuracy the electromotive force of a circuit in volts, the current in amperes, the energy in watts, etc.

VOLTMETERS AND AMMETERS

50. Among the best commercial **voltmeters** and **ammeters** are those in which the movement of the needle depends on the reaction between a fixed permanent magnet and a movable coil through which a current is caused to flow. Such a portable voltmeter and also an ammeter have already been described in *Elements of Electricity and Magnetism*. The Thompson inclined coil instruments depend for their action on the movement of an iron vane in a magnetic field set up by the passing current. Other instruments employ the principle of the varying length of a conductor as it is heated by a passing current.

51. These instruments are made either to *indicate* the values of the quantities to be measured or to *record* the values

on a moving paper dial. The two kinds are distinguished by the terms *indicating instruments* and *recording instruments*. Unless the current to be measured is very small, only a portion of it is allowed to flow through the ammeter. A resistance called an *ammeter shunt* is arranged to carry the larger part of the current, but as the portion through the instrument is always proportional to the total current, the ammeter may be calibrated to read the total amperes in the circuit. Similarly, when a very high pressure is to be measured, a known resistance is generally used in series with the voltmeter to keep the current down to the capacity of the instrument.

WATTMETERS

52. On direct-current circuits, the power, in watts, being used at any instant may be found by taking the product of the volts and amperes. Instruments known as *indicating wattmeters* automatically perform this multiplication and indicate the watts passing at any time. Other instruments known as *recording wattmeters* perform the same multiplication and also introduce the element of time; that is, they record the number of *watt-hours*, or *kilowatt-hours*, that have passed during a given time.

Fig. 24 (*a*) shows an assembled Thompson recording wattmeter with the cover removed; view (*b*) shows the rotating part, or armature removed from the meter. Fixed coils *a*, *a*, called field coils, are connected in series with one side of the circuit. Movable coils *b*, *b*, *b*, called armature coils, are wound across a suitable support, and are connected through commutator *c*, *c*, in series with a resistance and a so-called shunt coil *g* across the main circuit. Coil *g* consists of a number of turns of fine wire and is mounted on an adjustable brass frame *h* so that the coil can be moved in or out, that is, to or from the armature, so as to compensate for friction on light loads; the coils provide a magnetic field almost sufficient to move the armature when no current is flowing in the series-coils; hence a small load starts the meter. The moving element, or armature, is very similar

to a generator or motor armature except that no iron is used in the core. Shaft *d* has a hardened-steel pivot *n* at the lower end and a worm-gear *m* at the upper end. The position of the armature shaft can be seen in Fig. 24 (*a*); the pivot *n* rests on a jewel and the worm-gear *m*, as the armature turns, actuates a train of gears, that moves the hands on the dials. Current is conveyed to the movable coils through brushes *f*, *f*.

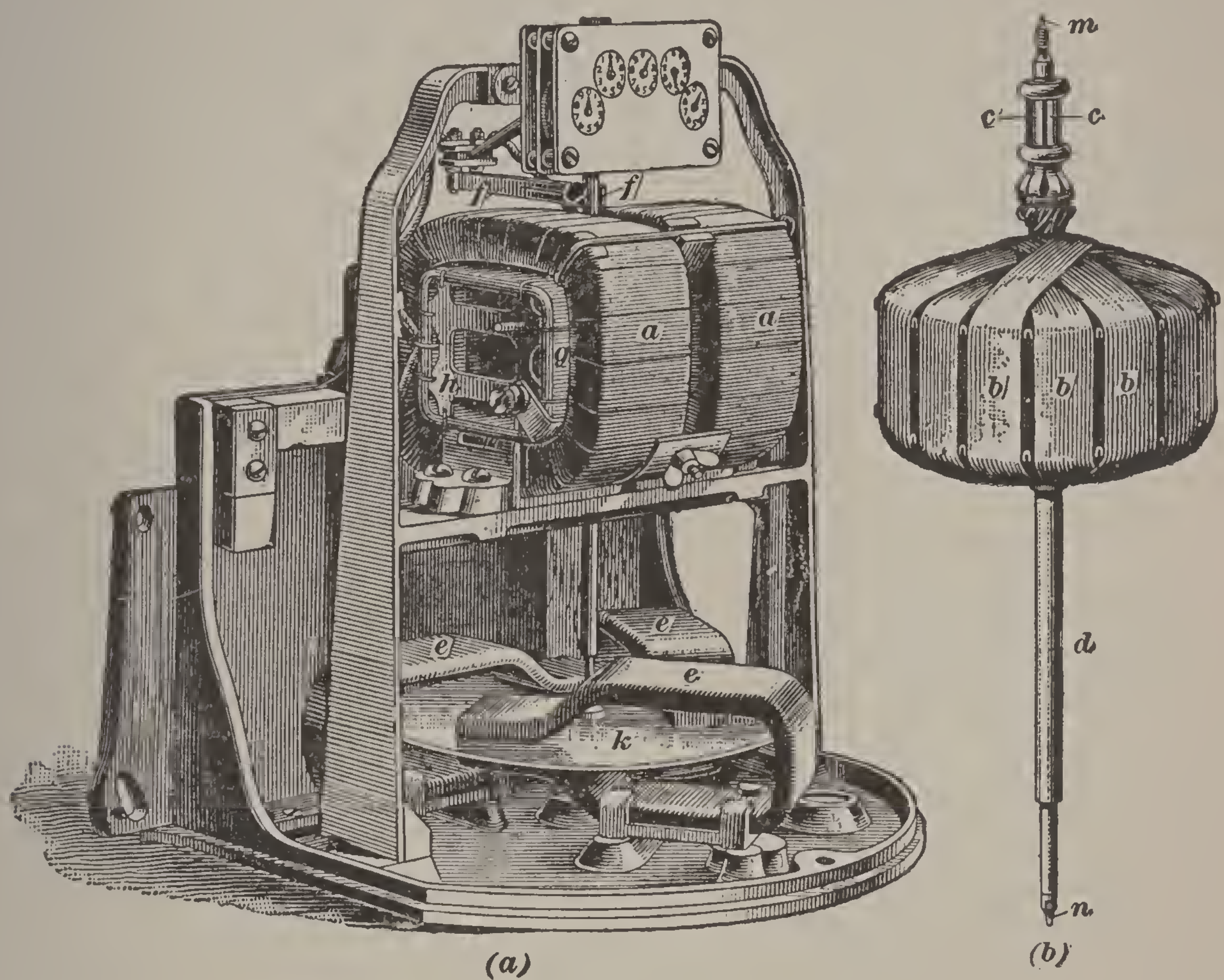


Fig. 24

A disk *k*, formerly made of copper but now made of aluminum, is connected to shaft *d*, which causes it to rotate between the poles of permanent magnets *e*, *e*, *e*.

53. Operation of a Thompson Recording Wattmeter.—As the disk *k* rotates, there are set up in it eddy currents that are directly proportional to the speed of rotation and that cause a retarding or damping effect. The torque of the armature, and consequently the speed, is proportional both to the amount of current through the fixed coils, or field coils, *a*, *a*, and the current through the movable, or armature,

coils b, b, b. The current through a, a is the current in the circuit being tested, or proportional to it, and that through b, b is proportional to the pressure of the circuit; hence the speed of the armature is directly proportional to the watts consumed in the circuit. This instrument is really a small electric motor with no iron in the magnetic circuit. Iron is not used, because its permeability is variable, depending on the degree of saturation. This meter will operate on either direct- or alternating-current circuits and will give accurate results if the commutator, pivot, and jewel are kept in good condition.

There are a number of other meters in common use, most of which are of the motor form. Some are made for use on alternating-current circuits only. Other instruments are sometimes used for making measurements of electric quantities, but those described are most commonly used around central stations.

SWITCHBOARDS

54. The **switchboard** is a necessary part of every plant. Its object is to group together at some convenient and accessible point, the apparatus for controlling and distributing the current, and the safety devices for properly protecting the lines and machines. Scarcely any two switchboards are alike in every particular; their layout and the type of apparatus used on them depend on the character of the system used, the number and size of generators, the number of circuits supplied, etc.

55. Construction.—Switchboards are now usually made of slate, marble, soapstone, or brick tile. Occasionally, where cheaper construction is required, a skeleton framework of seasoned hardwood is used, the wood being filled and varnished to prevent absorption of moisture. If connections are to be made on the back of the board, ample room should be left between the board and the wall, so that the work can be done without danger or discomfort. Switchboards are now usually built in panels, those carrying instruments for generators being known as **generator panels**, and those carrying instruments for feeder circuits, as **feeder panels.**

DIRECT-CURRENT SWITCHBOARDS

56. Railway Switchboard.—Fig. 25 shows a typical **direct-current switchboard** as arranged for electric railway operation on the ordinary 500-volt rail-return system.

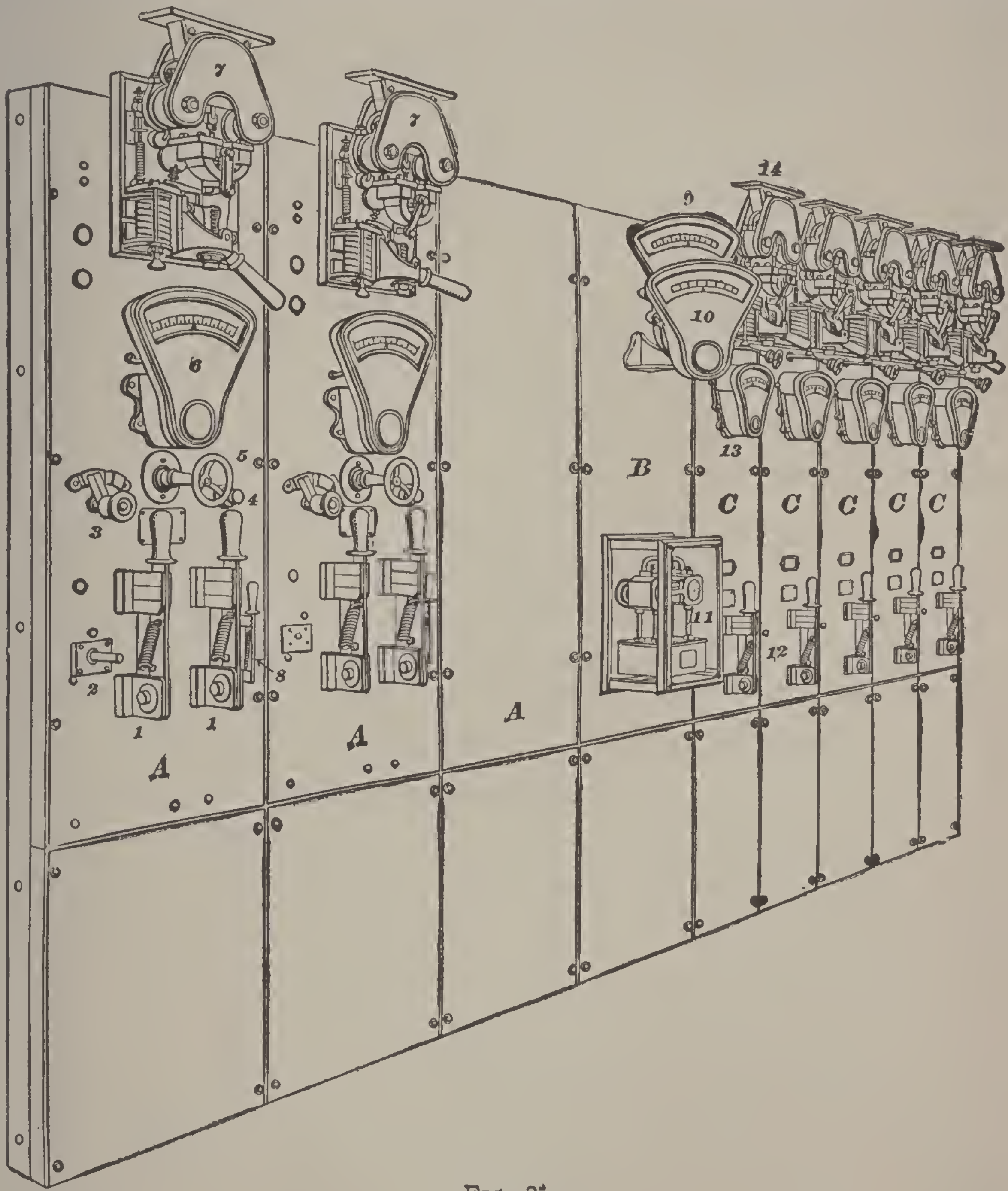


FIG. 25

The board consists of three generator panels *A*, *A*, *A*, one total-output panel *B*, and five feeder panels *C*, *C*, etc. One of the generator panels is left blank to provide for a future generator. Each *generator panel* is equipped with + and − main switches *1*, *1*, voltmeter plug *2*, field switch *3* for opening the field circuit of a generator and at the same time

closing a path for the field to discharge through a resistance pilot-lamp receptacle *4*, field rheostat operated by hand wheel *5*, ammeter *6*, circuit-breaker *7*, and station lighting switch *8*. The *total-output panel* carries a voltmeter *9* that can be connected to either machine by means of the voltmeter plug, a total-output ammeter *10* that indicates the combined current output of the generators; and recording wattmeter *11* that records the total output in kilowatt-hours. Each *feeder panel* is equipped with a single-pole feeder switch *12*, a feeder ammeter *13*, and a feeder circuit-breaker *14*. Since on a ground-return railway system the current returns through the rails, which are connected to the negative bus-bar, the feeders are connected to the positive bus-bar only, hence single-pole feeder switches are used.

Fig. 26 shows the connections for the board. Two feeder panels only are shown, and the instruments and switches are numbered to correspond with Fig. 25. If lightning-arrester reactance coils are used on the switchboard, they will be inserted as indicated on the left-hand feeder panel. The equalizer switches are mounted on pedestals near the generators and the equalizer connections are not brought to the switchboard. When the voltmeter plug is inserted in either receptacle, terminals *a*, *c* and *b*, *d* are connected, thus placing the voltmeter across either machine; the voltmeter connections are made at the lower terminals of the main switch, or "back" of the switch, so that voltmeter readings can be taken before a machine is thrown in parallel by closing the switch.

ALTERNATING-CURRENT SWITCHBOARDS

57. The arrangement of ordinary **alternating-current boards** is, in many respects, similar to that of direct-current boards. They are usually built up in panels in the same way as the boards previously described. Owing to the fact that alternators are generally separately excited, the switchboard contains some extra apparatus connected with the exciter that is not found on direct-current boards. The wiring and connections will also depend on whether single-phase or polyphase alternators are used.

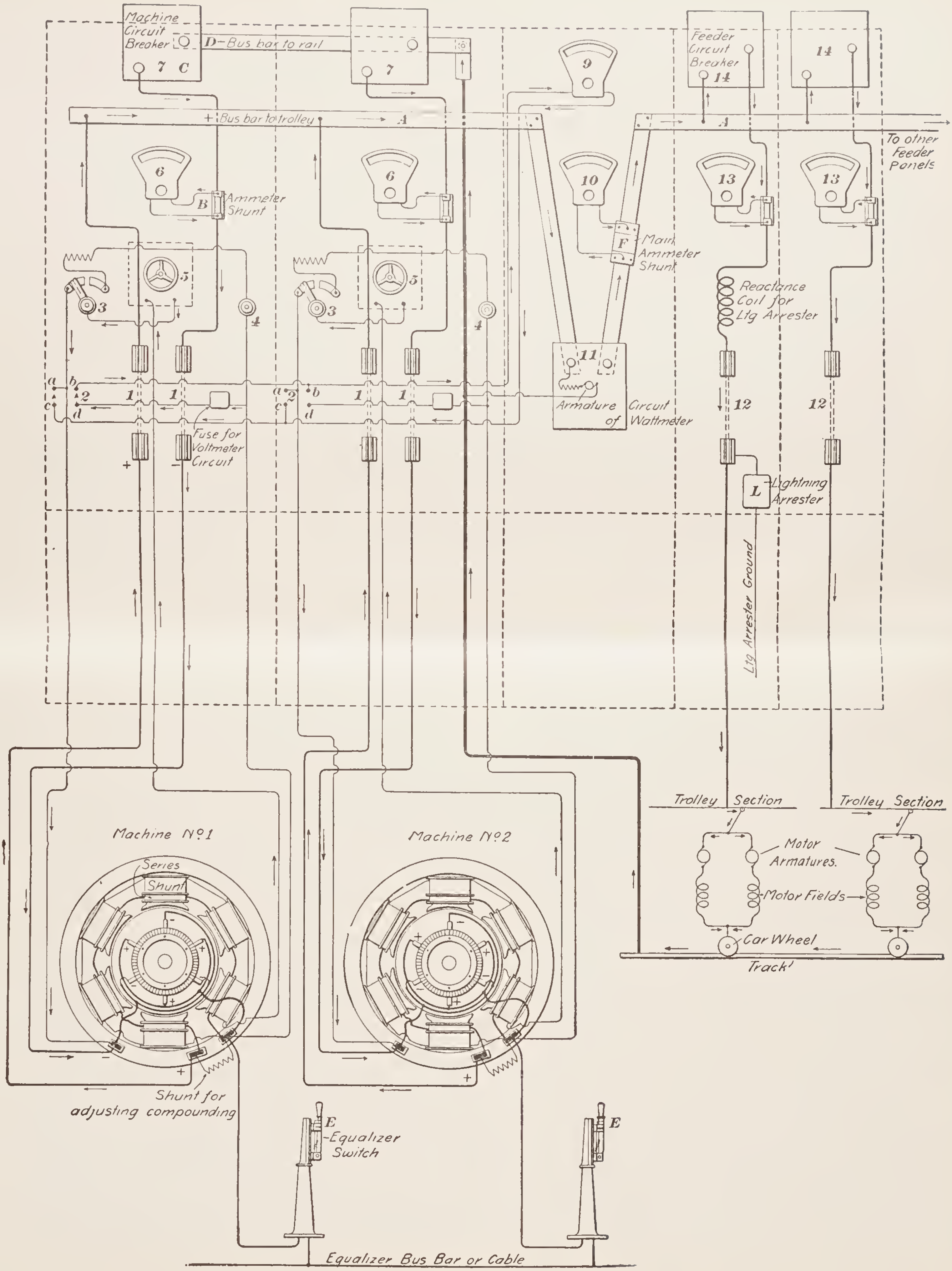


FIG. 26

ILT 277 BB 444 839B

95130

58. General Arrangement of High-Pressure Switchboards.—In low-pressure work, the switchboard consists of a group of slate or marble panels on which the switches, bus-bars, instruments, and all devices necessary for the control of the station output are placed. Such crowding of the parts is dangerous on a high-pressure board, and the tendency in large stations is to separate the high-pressure switches and bus-bars so that a short circuit on one part will not spread to others and result in a serious interruption of the service. The switchboard panels in this case carry only the instruments and small switches necessary for controlling the main switches that are usually operated either by compressed air, electric motors, or electromagnets. No parts carrying high pressure are exposed on the surface of the board, thus insuring safety to the attendant; a switchboard arranged on this plan occupies a large amount of space.

PERSONAL SAFETY FROM ELECTRICAL SHOCKS

59. It would be perfectly safe to handle high-pressure electrical conductors if, while doing so, *no part of the body should form an electrical connection between points at widely different potentials*. If a high-pressure generator is grounded either accidentally or on purpose, an electrical connection made through the body between any part of the generator, or any conductor connected thereto, and the ground, may cause a shock. It is therefore best, when handling machines or conductors on which there is a pressure of 500 volts or more, to use rubber gloves, or rubber shoes; even to stand on a piece of dry wood is sometimes sufficient. Tools, screw-drivers, pliers, wrenches, etc. with insulated handles are very convenient for such work. Even when standing on an insulator, never let but one bare hand come in contact with a *live* conductor at the same time. It is still safer to avoid handling high-pressure conductors as much as possible. The adage "Familiarity breeds contempt" applies with full force to electrical workmen, for those accidentally killed are nearly always the men who from long experience have become careless.

STORAGE BATTERIES

INTRODUCTION

60. Comparison Between Primary and Secondary Cells.—A **primary cell** consists of two unlike electrodes immersed in an electrolyte, whereby an electromotive force is developed between the electrodes, and an electric current is set up when the terminals of the electrodes are connected to an electric circuit. The direction of the current is from the positive terminal to the negative terminal. The flow of electricity is accompanied by chemical changes on the surface of at least one of the electrodes and, usually, of the electrolyte, as a whole. The quantity of the material altered by these chemical changes is proportional to the quantity of electricity, in ampere-hours, that flows through the circuit. When any of the materials entering into the chemical changes of the primary cell has been entirely altered, the cell is exhausted, or fully *discharged*.

61. The action of a **secondary cell, storage cell,** or **accumulator,** is fundamentally the same as that of a primary cell, but differs in this that when the secondary cell is discharged, either wholly or partly, the chemical action may be reversed and the storage cell restored to its original state. This reverse action, known as *charging,* is caused by passing a current through the cell in the reverse direction; that is, by letting the current enter at the positive terminal. The material of the electrodes that undergoes chemical changes during charge and discharge, called the *active material,* is generally supported on the surface or in openings, or pockets, of the electrode, which is then called a *grid*. The grid with its active material is called a *plate*. Each electrode in a storage cell con-

sists of one plate or of several plates connected in parallel. There is sufficient space between the plates of both electrodes to allow the plates of one to be inserted between the plates of the other, in this manner allowing positive plates to alternate with negative ones, and thus providing the shortest path for the current through the electrolyte.

Two types of commercial storage cells are in use: The *lead-sulphuric-acid cell,* sometimes called, simply, the *lead cell,* and the *nickel-iron-alkaline cell,* known as the *nickel-iron,* or *Edison, cell.* The names are derived from the chemical natures of the electrodes and the electrolytes.

62. Chemical Action of Lead and Nickel-Iron Cells.—In the **lead-sulphuric-acid cell,** the grids, both positive and negative, are of lead or of lead-antimony alloy. The active material of the positive plate when the cell is fully charged is *lead peroxide,* a chemical compound of lead and oxygen. The active material of the fully charged negative plate is metallic lead in a spongy, porous state. The electrolyte is a solution of sulphuric acid, formed by mixing 1 part of pure concentrated acid with 2.5 parts, by weight (4.5 parts by volume), of distilled water. The specific gravity of the electrolyte—that is, the ratio of the weight of a given volume to that of an equal volume of water—is about 1.2.

The lead and the oxygen in lead peroxide are chemically combined into a substance from which neither can be separated except by a chemical process. The lead peroxide undergoes such a process during the discharge of the cell; half of the oxygen is transferred from the positive to the negative plate, producing on each plate *lead monoxide,* which is another chemical compound of lead and oxygen. At the same time, the sulphuric acid is decomposed into water and a gas called *sulphur trioxide;* this gas combines with the lead monoxide, forming *lead sulphate* on each plate. The active material on each plate of a fully discharged lead cell is therefore lead sulphate; and the electrolyte has become weakened because of the presence of additional water formed by the decomposition of some of the sulphuric acid.

During charge, the reactions are reversed: the acid is restored to the electrolyte; the active material of the positive plate is oxidized to lead peroxide, and that of the negative plate is reduced to spongy lead.

It will be noted that the specific gravity (strength) of the electrolyte *decreases* during discharge and *increases* during charge, thus furnishing an indication of the state of discharge of the cell, which state may be ascertained by means of a hydrometer.

63. In the fully charged **nickel-iron cell,** the active material of the positive plate is *nickel peroxide,* and that of the negative plate is finely divided metallic iron. The electrolyte is a dilute solution of *potassium hydroxide,* or *caustic potash.* A small quantity of *lithium hydroxide* is added to the electrolyte to improve the capacity of the cell.

During discharge, part of the oxygen of the nickel peroxide is dissociated and transferred to the negative plate, where it combines with the iron to form ferrous (iron) oxide; but the composition of the electrolyte remains unchanged. Unlike the electrolyte of the lead cell, the potassium hydroxide serves merely as a carrier of oxygen from one electrode to the other. When the cell is fully discharged, the active material of the positive plate is nickel oxide and that of the negative plate, ferrous oxide.

CONSTRUCTION AND CHARACTERISTICS OF STORAGE CELLS

CONSTRUCTION

64. Lead Cell.—The component parts of the lead cell are *the element,* comprising the *positive-plate group* and the *negative group,* including connecting straps, or bus-bars, and the *separators;* the *plate supports* (in lead-lined tanks); the *container,* consisting of a glass or a rubber jar or a lead-lined wooden tank; the *electrolyte;* the *cover;* and the *insulating cell support.*

Fig. 27 shows a lead cell with a rubber-jar container, part of the cell being shown broken away in order to display the arrangement of the interior. The positive plate is at *a*; *b* is a rubber separator; and *c*, a wooden separator. The plates rest on ribs *d* on the bottom of the jar. This type of cell is provided with a hard-rubber cover which has a hole for filling that can be plugged with a soft-rubber stopper *e*, having a small vent hole in the center.

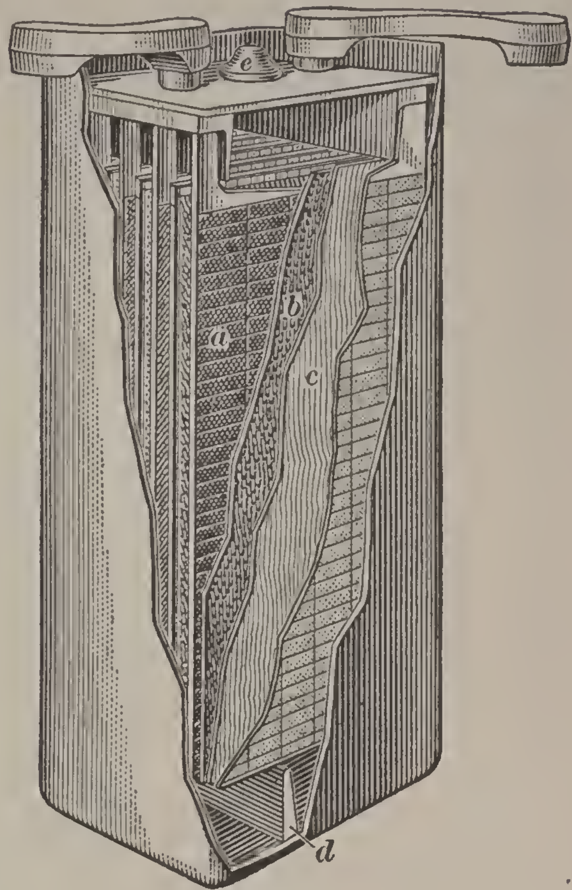


FIG. 27

Cells in glass jars are supported on shallow trays of wood or glass. The most satisfactory support for cells with lead-lined tanks is the *oil insulator*, an annular trough, half filled with oil and covered with a lead cap. The glass trough rests on an earthenware pedestal, four of these insulators supporting one cell.

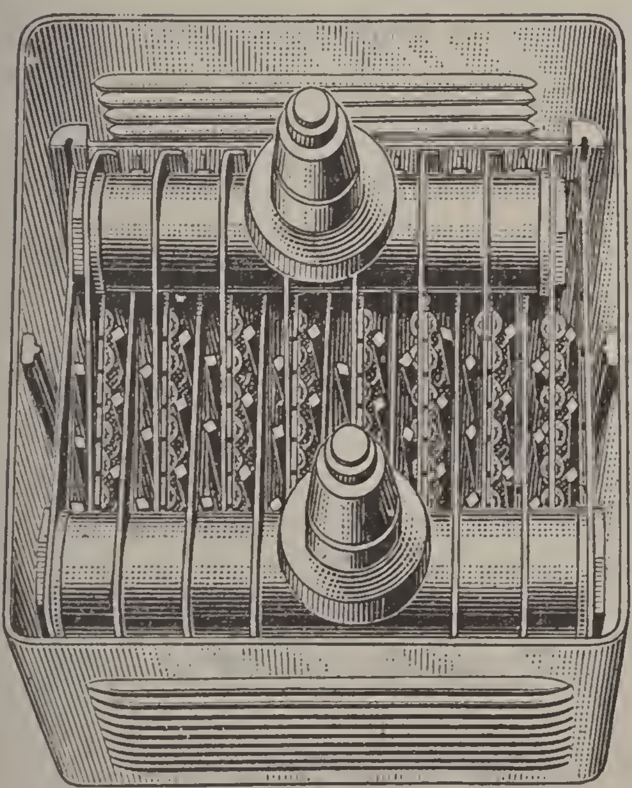


FIG. 28

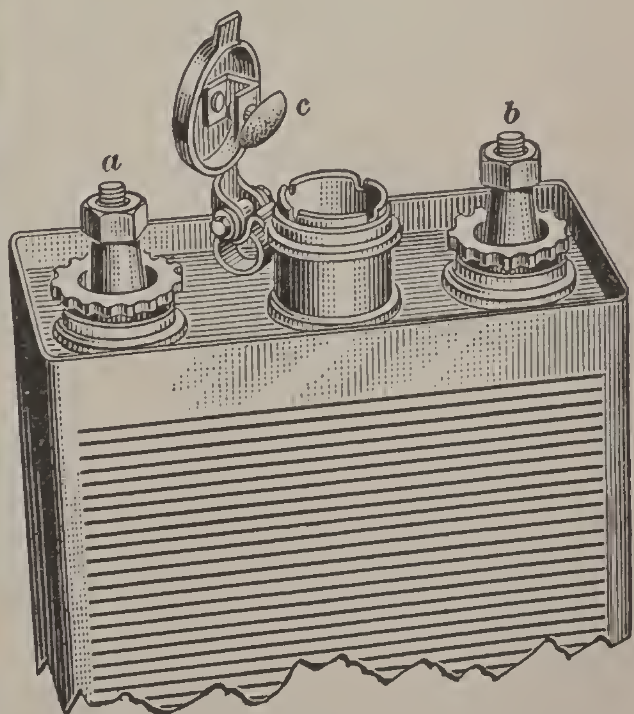


FIG. 29

65. Nickel-Iron Cell.—The plates of the nickel-iron cell are separated from each other by vertical strips of hard rubber, square in section, as shown in Fig. 28, which is a view of a cell from above. Sheets of hard rubber are inserted between the outside negative plates and the jar. The plates rest on hard-rubber bridges on the bottom of the jar. The container, Fig. 29, is a box made of nickel-plated sheet steel, corrugated to give added stiffness, the cover being welded on after the element is in place. The two terminal posts *a* and *b* pass through circular openings provided with rubber bushings. The central opening, used for filling the cell, is closed by a spring cap containing a valve *c* which allows the gases to escape, but excludes the external air.

CHARACTERISTICS

66. Lead Cells.—The **capacity** of any storage cell, expressed in ampere-hours, is the product of the rate of discharge in amperes by the number of hours the cell will maintain that rate at full charge. With lead cells the ampere-hour capacity varies with the rate of discharge, being less at high rates than at low rates. The capacity of a standard stationary cell is based on the *normal,* or *8-hour,* rate of discharge.

The **external voltage** of a cell is that which can be measured by connecting a voltmeter across the cell terminals; it is equal to the *internal voltage* minus the drop through the internal resistance. When the cell is delivering no current, the internal and external voltages are equal.

The open-circuit voltage of the lead cell is from 2.05 to 2.08. During discharge the external voltage drops below the open-circuit voltage by an amount that varies with the rate and duration of the discharge. The final voltage at the end of discharge at the normal rate is 1.75.

67. When a charging current is passed through a cell, the instantaneous rise of voltage above the open-circuit value is due to the internal resistance, and the subsequent gradual rise is due to polarization caused largely by the acid becoming

stronger in the pores of the plates. When the charge is nearing completion, a further rapid rise in voltage is caused by the collection of bubbles of oxygen and hydrogen at the surfaces of the positive and negative plates, respectively—the result of the electrolyte being decomposed when practically all the active material has been fully charged. The final voltage at the end of a charge at normal rate, with the charging current still flowing, is from 2.6 to 2.8 for new cells. For older cells the voltage may not exceed 2.4 to 2.5.

68. The specific gravity of the electrolyte decreases during discharge and increases to the initial value during charge. In stationary cells, the maximum value is about 1.210, which drops to 1.170 or 1.180 at the end of a complete discharge. When this range is once known the state of charge of a cell may be ascertained at any time by observing the specific gravity by means of a hydrometer. On movable cells, the maximum specific gravity is about 1.275.

The foregoing data are based on a cell temperature of 70° F. The capacity of a cell decreases with a decrease in temperature. The loss amounts to about .6 to 1 per cent. of the 70° capacity for each degree reduction in temperature.

69. Nickel-Iron Cells.—The rated capacity of the nickel-iron cell is based on a 5-hour discharge rate. The actual capacity in ampere-hours, however, is but little affected by variation of the discharge rate, provided no limit is set to the final voltage. The open-circuit voltage is about 1.5 volts when fully charged, and the voltage at the end of discharge is rarely carried below 1. The internal resistance is approximately three times that of the lead cell of the same capacity and voltage and its efficiency is lower than that of the lead cell under similar circumstances.

The principal advantages of the nickel-iron cell are: durability, mechanical ruggedness, and ability to withstand neglect and abuse without injury. It is best adapted for service at low discharge rates where cost of charging current is low, and where light weight is important.

CHARGING STORAGE BATTERIES

70. Methods of Controlling Charge.—The charging current of a storage battery can be controlled by means of a rheostat, by varying the voltage of the source of the charging electromotive force, or by means of a booster. Only the first two will be briefly considered in this Section.

71. Charging Through Resistance.—A charging rheostat is connected as at *r*, Fig. 30, where the voltage of the charging source is greater than that required for the number of cells in series. In such cases, the voltage of the charging

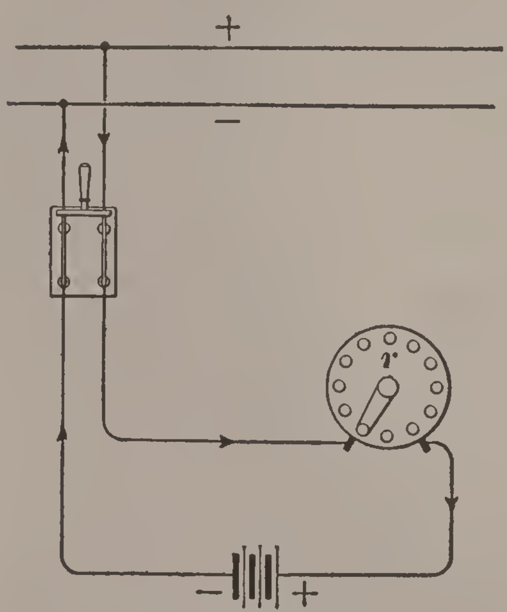


Fig. 30

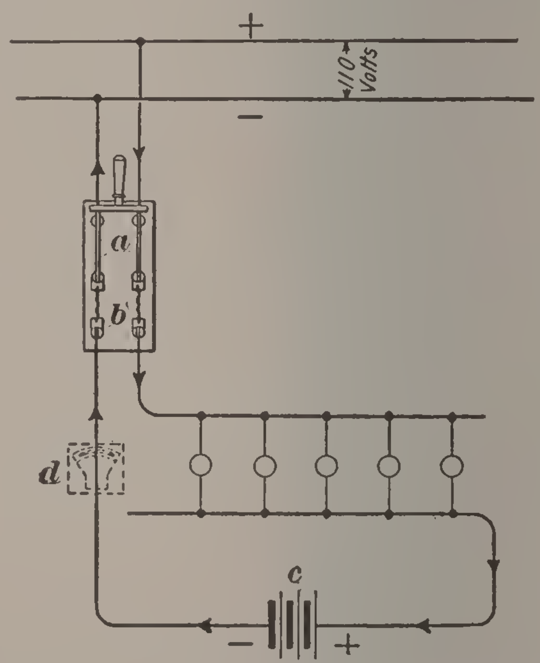


Fig. 31

source should be approximately equal to the final voltage of the battery at the end of the charge; the rheostat serves to reduce this voltage to that required at the beginning of the charge, and the resistance is gradually cut out as charging proceeds, so as to maintain the proper strength of the charging current.

A few small cells can be conveniently charged from a lighting circuit through lamp resistance. The current consumption of the lamps will then determine the charging current. Fig. 31 shows a method of connecting a battery to charge from a 110-volt circuit through five 110-volt, 16-candlepower,

$\frac{1}{2}$-ampere lamps connected in parallel, the charging current being practically $5\times\frac{1}{2}=2\frac{1}{2}$ amperes. The charging current passes through the switch *a*, the fuses *b*, the battery *c*, and the ammeter *d*, if one is used. The lamps may be connected in either lead to the battery.

72. Charging by Variation of Charging Electromotive Force.—The small storage cells used in miners' lamps may be charged by an arrangement similar to that shown in Fig. 30, except that the cells are arranged in parallel instead of in series. This is made necessary by the fact that the lamps are submitted for charging at irregular times, and that a series connection would require a constant readjustment of voltage. The usual arrangement is to provide two bus-bars from which the cells may be suspended for charging, the current at the required pressure being provided by any convenient means, such as a motor-generator.

73. Storage batteries for mine locomotives may be charged from the lighting circuit, usually of 250 volts, or by means of a motor-generator set. The latter method seems to be preferable, as it involves less loss of energy. For example, supposing the battery to consist of 48 cells, and that the final charging voltage is 2.6, the voltage required for charging the battery will be $48\times2.6=125$ volts, nearly. A motor-generator may be adjusted to deliver a current of this voltage; but, if the lighting circuit is to be employed, the pressure of the charging circuit will have to be reduced by 125 volts in the rheostat, showing that the latter will consume one-half of the available energy.

Complete motor-generator sets and automatic switchboards suitable for charging purposes are furnished by the manufacturers of electric locomotives.